Course 3012

Radio Mechanics

Volume 3. *Airborne Radio Aids To Navigation*

Part A

USAF Extension Course Institute

Air University

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Radio Mechanics

Volume 3. ***Airborne Radio Aids To Navigation***

Part A

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Air University

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RADIO MECHANICS

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Preface

You will begin your study of "nav aids" in this part of volume 3 with an introductory chapter on the principles of avigation (aerial navigation), which includes the use of the magnetic compass, radio compass, and radio range system in homing and position-finding.

The second chapter presents the theory and operation of the AN/ARN–7 radio compass receiver. The electrical functions of the various circuits in the set are analyzed for the three modes of operation (antenna, loop, and compass).

Chapter 3 presents another radio compass receiver, the AN/ARN–6 which performs the same functions as the AN/ARN–7. It was designed especially for fighter aircraft and represents an improved design in radio compass receivers.

You will study the sets with the aid of the complete schematic diagrams. Simplified diagrams will be given where they make understanding easier.

It is assumed you have a good understanding of radio fundamentals and have completed the preceding volumes in this course.

At the end of each chapter you will find several review questions. These are study aids, and correct answers are provided at the end of the pamphlet. Please do not submit your answers to the USAF Extension Course Institute for grading nor enter into correspondence concerning these questions.

Keep this pamphlet for your own use.

This course is published in a series of eight volumes with a total credit value of 264 hours (88 points). Volume 3, Part A is valued at 21 hours (7 points).

Contents

Chapter 1

PRINCIPLES OF AIR NAVIGATION

BASICALLY, navigating in the air is no different from navigating through water. The methods used by mariners in sea travel are still used today. The compass is still an important aid to all navigation. The stars and the sextant are still used to locate the position of a ship or aircraft anywhere on the earth. In fact, the *old* methods are the only methods for navigating in the vicinity of the poles, where radio reception becomes very unreliable.

On the other hand, in many countries today and especially in the United States, Canada, and Europe, the application of radio principles to air navigation has been refined to such a point that a practically new science has been developed for air navigation alone. This science has recently been termed *avigation* and can be defined as the science or art of conducting aircraft in flight from one point to another.

You must remember that radio is not replacing other methods of avigation but is helping to make air navigation much more reliable and dependable and easier for the men who fly the aircraft.

1. Need for Air Navigation

The early flyer found his way by means of landmarks. This was satisfactory for short daytime flights within sight of the ground, but as aircraft design improved and air transportation grew in importance, the need arose for exact schedules to handle traffic by day or night, over water as over land, and in foul weather as in fair. The old hit-or-miss method of navigation was no longer adequate; it had to be replaced by newer and more precise methods.

The airman naturally turned to the science of marine navigation, but some of the equipment was too heavy and bulky for aircraft. Also, some of the marine navigator's techniques were too slow for use in fast-moving aircraft. Some problems peculiar to aircraft had to be solved independently. Thus, avigation progressed by the improvement of old instruments and methods and the invention of new ones.

A highly organized system of Federal radio and lighting aids along established airways of this country now makes possible the efficient operation of commercial airline schedules. These aids simplify the navigation problem, making it possible to navigate without a complete knowledge of such factors as wind, variations, and deviation. Therefore, on a commercial airliner the pilot and copilot can do their own navigation. This is also true for military aircraft under ordinary circumstances in peacetime. The essential piece of equipment that makes this possible is the radio compass receiver, which you will study in this volume.

Military aircraft, however, must often fly where radio aids are not available or cannot be used because of enemy interception, so that different techniques must be used. The transport pilot flies straight-line flights, but the bomber pilot must fly his course to avoid enemy installations. The air-sea rescue pilot must make a predetermined flight pattern to cover fully the area to be searched. The fighter pilot must be able to navigate under all conditions, performing over-water rendezvous and interception problems while performing his duties as pilot. Despite these differences, all pilots use basically the same navigational methods.

In navigation you have three major problems. You must be able to determine (1) the *position* of the aircraft at any time, (2) the *time* at which the aircraft will reach any position, and (3) the *way to head* the aircraft to reach any desired position.

These three problems can be solved when you know the position of the point of departure, the direction of flight, the wind effect, the speed of the aircraft, and the length of time it has been flying in the known direction of flight. The procedure used to solve the basic problems from the above information is termed *dead reckoning.*

Dead reckoning is essential to navigation. It is the only method of solving the second and third problems. Map reading and radio can solve only the problem of location. In the United States and in Canadian territory near the border, however, it is a routine procedure to fly from one place to another by following a radio beam with the compass receiver or the radio range receiver. The location of the radio range stations that transmit the directed beam, their frequencies, and all other

pertinent facts needed by the pilot in flight are listed in periodically published *Radio Facility Charts.*

During flight the pilot simply watches the compass indicator; as long as the pointer is in line with the index of the indicator, the aircraft is heading in the desired direction along some airway that leads him to his destination. Throughout the flight, the pilot steers the plane in whatever direction necessary to keep the indicator pointer in line with the index. The index is in turn alined with the center line through the nose and tail (longitudinal axis) of the aircraft, but it can be adjusted to compensate for deviations caused by distortion of the radio field pattern.

2. The Magnetic Compass

The magnetic compass is the basic navigational instrument. Its operation and use depend upon the fact that an undisturbed magnetized needle, free to rotate at its center, will always point to the earth's magnetic pole (near the geographical north pole). The magnetic compass is used to determine the proper heading of the aircraft. It is an essential aid to radio direction finding.

Heading. The direction in which an aircraft is pointed is its heading. This direction may be expressed with relation to *true north* (TN) or *magnetic north* (MN). Heading measured with relation to true north is *true heading* (TH). Thus, true heading is the angle measured from true north clockwise to the forward end of the aircraft's longitudinal axis. Heading measured with relation to magnetic north is *magnetic heading.*

Principles of Operation. As previously mentioned, a magnetized needle, free to rotate, will take a position such that its magnetic axis is parallel to the lines of force of the earth's magnetic field, forming a simple compass.

Although the magnetic field of the earth lies roughly north and south, the earth's magnetic field does not coincide with its geographic poles. At most places on the earth's surface, a needle that is lined up with the earth's magnetic field will not point to true north (geographic north pole). Also, local magnetic fields resulting from mineral deposits and other conditions distort the earth's magnetic field and cause an additional error in the position of the needle with reference to true north. These two types of errors are called *variation* and *deviation.*

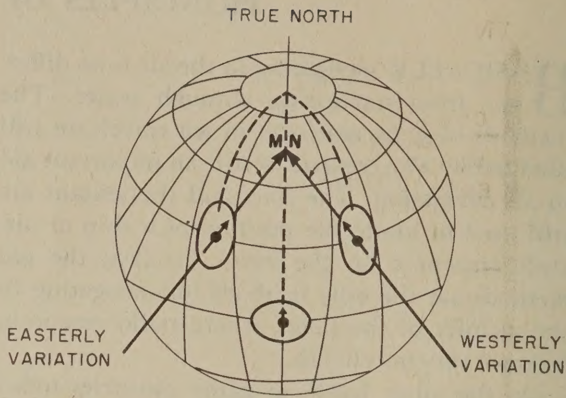


Figure 1. Variation.

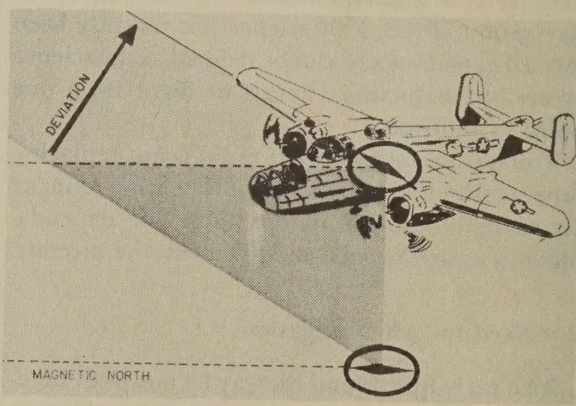
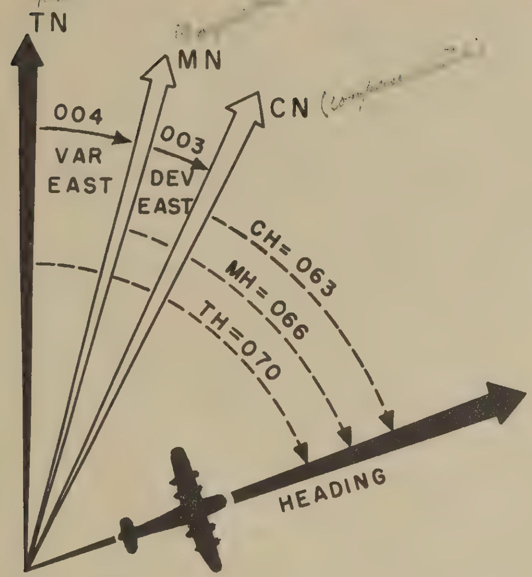


Figure 2. Deviation.

The difference between true north and the direction in which an undisturbed compass needle points is called variation. Variation is different at different points on the earth's surface and is shown on charts as broken lines (called *isogonic* lines) connecting points of equal variation. (See fig. 1.)

The difference between the direction indicated by an undisturbed magnetic compass and that indicated by a particular compass in a particular aircraft is called deviation. (See fig. 2.) The direction the compass needle actually points is called *compass north* (CN), and the *angle* the aircraft heading makes with compass north is called *compass heading.*

When the aircraft's heading is corrected for deviation, it is called magnetic heading. When the compass heading is corrected for both deviation and variation, you have the true heading of the aircraft, which is the direction usually used



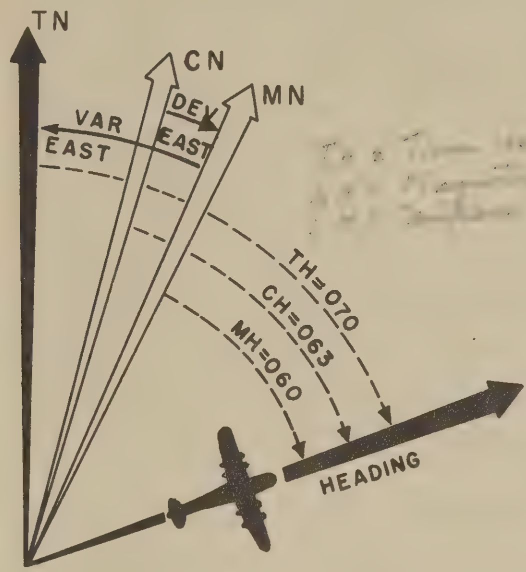


FIGURE 3. Heading.

in flight. (See fig. 3.) The pilot will find the correction for deviation on the compass correction card and the correction for variation in the aeronautical charts which are carried in the aircraft.

To make the corrections, it will be necessary to know whether to add or subtract the angles of deviation and variation to obtain the aircraft's true heading. To correct for an *easterly deviation* (the compass needle points to the east—clockwise—of magnetic north, making the angle between the axis of the aircraft and the needle smaller than it should be), *add* the amount of deviation to obtain the correct magnetic heading. For *westerly deviation,* the procedure is exactly opposite: simply *subtract* to obtain the correct magnetic heading.

Likewise, to correct for an *easterly variation* (the compass needle, corrected for deviation, points to the east of true north, making the angle smaller than the true angle), *add* the amount of variation to obtain the true heading. For *westerly variation,* the procedure is exactly opposite: simply subtract to obtain the correct true heading.

Use of the Compass. Several types of magnetic compasses are used in aircraft. Although they differ in construction, each has three basic parts:

1. Instead of a simple magnetized needle, there is a circular card, free to turn in a horizontal plane, with two magnets mounted on its lower surface.

2. A *lubber line,* or reference mark, fixed with relation to the aircraft, represents the heading.

3. A scale of degrees known as the *compass rose* is used to measure the angle from the lubber line. This angle is the compass heading. The compass rose may be on the card or separate from it.

Compass heading is of interest in navigation only as a means of determining true heading. You use the compass in two different ways:

1. You read the compass and then compute the true heading of the aircraft. Therefore, you must know how to apply variation and deviation to compass heading to find the true heading.

2. Knowing the true heading which you want to fly, you watch the compass to be sure you are flying the correct true heading. Therefore, you must know how to apply variation and deviation to true heading to find magnetic heading and compass heading.

Compass Error. The compass needle or card is made to turn freely only in a horizontal plane, and only in that plane will it read accurately. Owing to the vertical component of the earth's magnetic field (the compass is designed to respond only to the horizontal component of the earth's magnetic field), the needle or card will be pulled from its horizontal plane to form an angle with the horizontal. This angle is called *dip* and is the direction of the earth's magnetic field in a

vertical plane, just as magnetic north is its direction in a horizontal plane. Dip varies from 90° at the magnetic poles to 0° at the equator.

The compass accuracy is also affected when an aircraft suddenly changes its speed, direction, or attitude. These shortcomings can be partially overcome by the use of gyrostabilized compasses.

Within 300 miles or so of the poles, the compass is practically useless because the horizontal component of the earth's magnetic field is zero at the poles. The pilot or navigator then has to depend on *celestial navigation,* which is the only reliable means of fixing an aircraft's position and direction finding in the polar regions. This subject is not included in this course.

3. The Radio Compass

The magnetic compass, after correction, indicates only the direction in which the aircraft is headed; it does not give any information about the position of the aircraft. In contact flying, of course, the position can be determined by landmarks. Position can also be determined by celestial naviation and by dead reckoning. Only dead reckoning, however, can be used in blind flying, and it is subject to various errors. The radio compass, on the other hand, affords a simple, accurate, and quick means of position finding at all times, but it also has its limitations.

The radio compass is simply a sensitive receiver. Its operation and use depend upon its ability to pick up a radio wave sent from a transmitting station and to indicate its direction. The radio wave may be sent from any transmitter whatever within the frequency range of the compass receiver. These transmitters are mainly broadcast stations, radio range stations, control tower stations at landing fields, and airborne transmitters.

Characteristics of a Loop Receiving Antenna. The operation of a radio compass depends mainly on the characteristics of a loop antenna. The loop antenna gives maximum reception when the plane of the loop is parallel to, or in line with, the direction of wave travel. As the loop is rotated from this position, the volume gradually decreases, reaching a minimum when the plane of the loop is perpendicular to the direction of wave travel.

These characteristics of a loop antenna are due to the fact that the input from a loop antenna to a receiver is the resultant of the opposing voltages in the two halves of the loop. When the plane of the loop is in line with the transmitting station, the radio wave will induce a voltage in the side nearest the station before it does the other. This slight time delay results in a phase difference between the voltages induced in each half of the loop and a maximum resultant voltage at the loop terminals. Therefore, the resultant current flow through the antenna transformer will develop a maximum signal input to the receiver.

When the plane of the loop is perpendicular to the direction of wave travel, both sides of the loop are the same distance from the station, so that the radio wave induces the same voltage in each half. These voltages, being equal and opposite, cancel each other. Thus, there is no (or minimum) current through the transformer and no (or minimum) signal input to the receiver. Figure 4 shows the loop position for maximum pick-up, and figure 5 shows the minimum pick-up position. Figure 6 shows the radiation pattern of the loop antenna viewed from above.

Because it is much easier to determine the exact location of the minimum, or *null,* position than that of the maximum signal, the null position of the loop antenna is used for following a radio wave to its source and for direction finding.

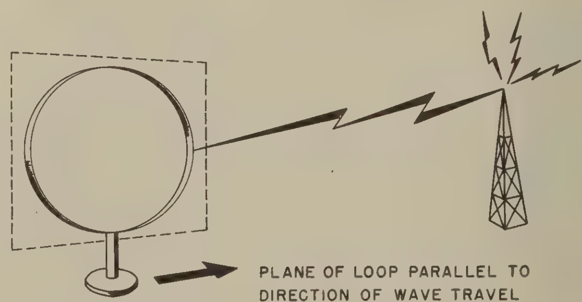


FIGURE 4. Loop Antenna at Maximum Position.

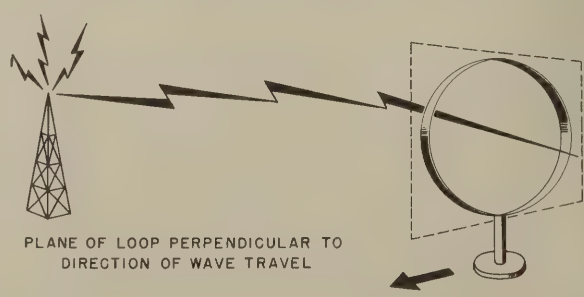


FIGURE 5. Loop Antenna at Minimum Position.

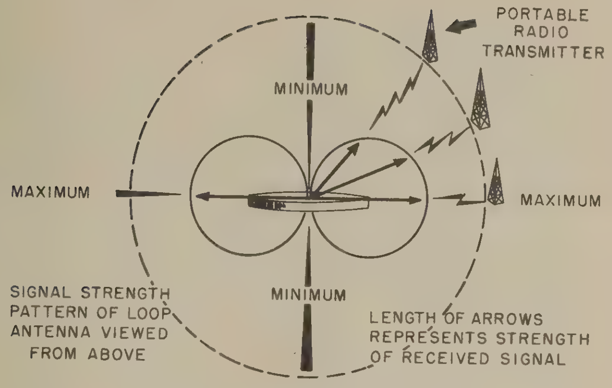


FIGURE 6. Loop Radiation Pattern.

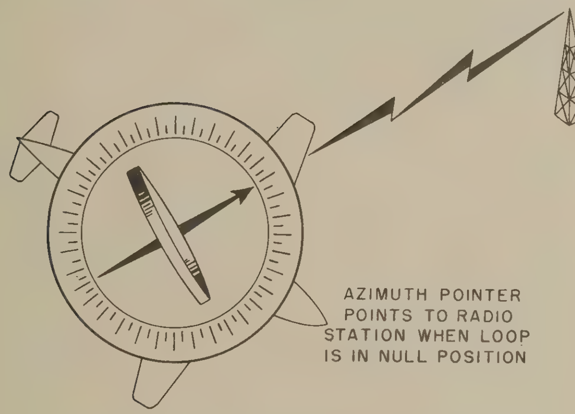


FIGURE 7. Indicator Position at Loop Null.

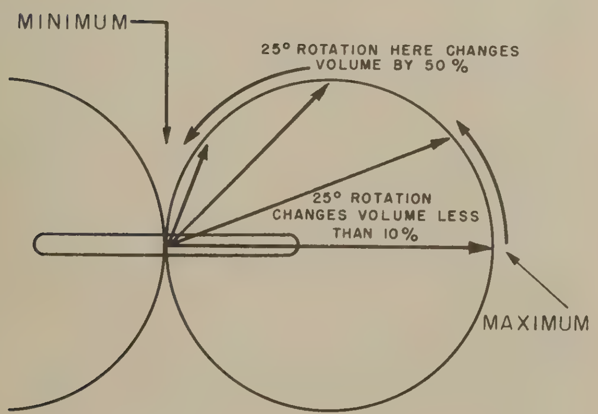


FIGURE 8. Minimum Versus Maximum Sensitivity.

Figure 7 illustrates the position of the compass indicator at the loop's null position. With a well-designed loop antenna, the exact minimum can be obtained within one-half a degree of loop rotation, whereas it is difficult to obtain exact maximum within several degrees of loop rotation. This is clearly illustrated in figure 8.

It is easy for you to visualize that between one maximum and one null position of the loop there is 90° of rotation (¼ turn). During that time, one leg of the loop will be nearer the signal source and will therefore determine the direction of current flow until the null point is reached. That is, the current will change from a maximum to a minimum value in one direction.

As we continue to rotate the loop in the same direction past the null point, however, the other leg will now be nearer the signal source, so that the resultant loop voltage and the current flow through the antenna transformer will be in the opposite direction. To put it another way, as the loop is rotated past a null point, the phase of the resultant voltage shifts 180°.

When the loop is again parallel to the signal source, we have rotated the loop one-half a turn and have again reached a maximum position. Thus, during one complete revolution there are two null points and two maximums. This is known as the 180° ambiguity, which means that if the loop alone is used for direction-finding, the pilot cannot actually determine whether the station is directly ahead of him or directly behind him. There is an aerial maneuver the pilot can perform to determine the true from the false null, but that is no longer necessary since the false null has been eliminated by the use of a sense antenna.

Sense Antenna. The sense antenna is a stub-mast or fixed-wire antenna. It has a nondirectional field pattern; that is, it radiates or receives equally in all directions. Its radiation pattern is therefore circular (looking down on the top of a stub-mast antenna).

When the figure-8 field pattern of the loop antenna and the circular field pattern of the sense antenna are combined, the resultant field pattern is a cardioid (heart-shaped), which means there is a null point on only one side as shown in figure 9.

Since the phase of the resultant loop voltage is opposite for stations from the opposite side of the loop, at any instant the voltage in one leg of the loop will be in phase with the sense-antenna voltage and the voltage in the other leg will be out of phase to produce the resultant voltage as shown in figure 9. It is apparent in figure 9 that voltages from stations on the right side of the

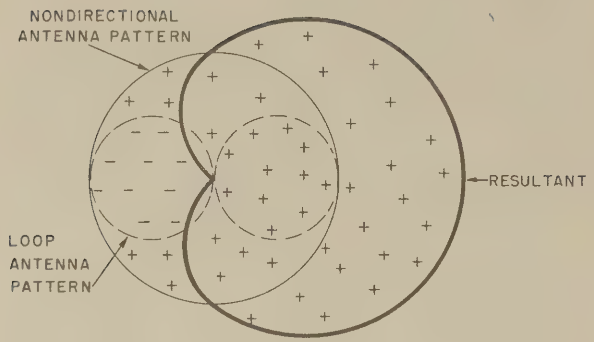


FIGURE 9. Loop- and Sense-antenna Field Patterns.

loop add and those from the left subtract. The opposite could also happen; in either case, it depends on the connections to the receiver.

At this point, you may wonder how the 180° ambiguity is solved. In the compass receiver, the resultant antenna current is fed through two loop-control tubes that cause an electric motor to rotate the loop automatically to the proper null. A more complete explanation of the radio principles and circuits involved will be given in chapter 2, where you will study radio compass receiver AN/ARN–7.

4. Air Navigation Systems

To navigate an aircraft with the aid of a radio compass receiver, it is necessary to have a system of radio airways criss-crossing the entire country. These airways are the *on-course* signals transmitted by a chain of over 400 radio range stations operating on a frequency between 200 and 400 kilocycles. To keep interference between stations at a minimum, the power output of radio range stations is kept low.

Antenna Systems. The direction in which on-course signals are radiated is largely determined by the antenna system. Most range stations employ either a loop or a tower system.

Since the radiation pattern of a loop antenna is a figure-8 pattern, two loop antennas may be placed at right angles to each other to produce two figure-8 patterns at right angles (see fig. 10). The regions of overlapping of the four sectors form the courses or zones.

As previously mentioned, the figure-8 field-strength pattern of the loop is due to the fact that one side of the loop is 180° out of phase with the other. Two vertical towers fed 180° out of phase will also produce a figure-8 pattern. Therefore, four towers may be arranged so that they will produce the same pattern as two loops. The advantage of the tower system is that its on-course signals are accurate even at night for its entire range; whereas the signals of the loop system are not reliable at night beyond 30 miles.

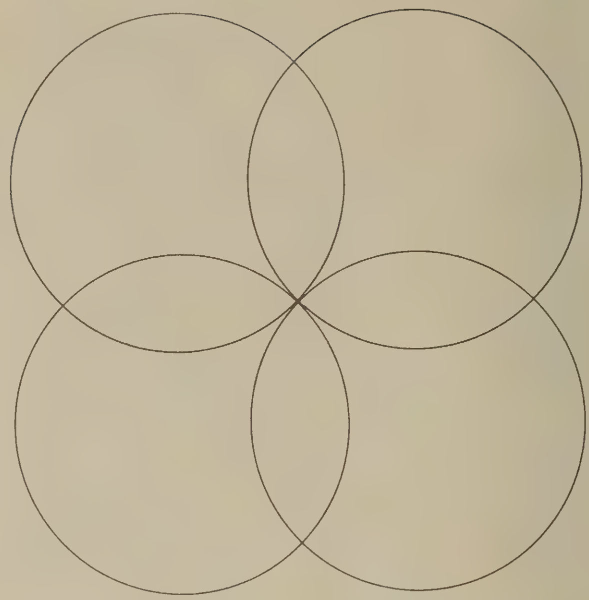


FIGURE 10. Radiation Pattern of Two Loop Antennas at Right Angles.

The transmission over one pair of towers is keyed with an A signal, and the other pair is keyed with an N signal. In the zones both signals are heard, but there are narrow lanes (3° wide) within the zones where the A and N signals are equally strong. In the lanes, the two signals are not heard individually but blend to give a steady tone, the on-course signal.

In the regions of overlapping, on either side of the 3° lanes, both the A and N signals can be heard, but one is stronger and predominates, depending upon whether you are to the right or left of the on-course lanes. These are called the bisignal zones (see fig. 11). When using the radio range, the airplane is generally flown in the bisignal zone along the right side of the on-course signal.

Directly above the radio range station, where the four courses intersect, there is an area the shape of an inverted cone, called the *cone of silence*. Within this area practically no signal is

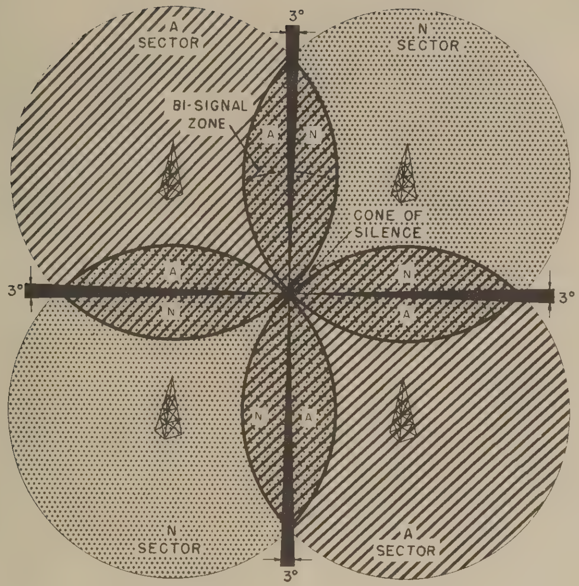


FIGURE 11. Radiation Pattern of 4-tower Radio Range Systems.

heard. At usual flight altitudes, the cone of silence can be recognized by the rapid increase of signal volume as you approach it, a quick fade-out as you enter it, and a quick increase in volume followed by a rapid decrease as you leave it.

Each range station has a 2- or 3-letter identification signal which is transmitted twice every half-minute, alternately, over each set of antennas.

The four range courses are not necessarily at right angles. They generally have to be turned at various angles to make them line up with the courses of adjacent stations to form continuous airways. This is done through phase shifting or power changing. The phase can be shifted by inserting inductance and capacitance elements in series with the transmission lines. Power can be shifted by reducing the energy in one of the transmission lines.

The range stations with loop or 4-tower systems cannot transmit voice (weather reports) and range signals at the same time, because none of the antennas are continuously connected to the transmitter. Each is keyed with the A and N signals. Therefore, while voice broadcasts are being made, the range signals are suspended.

Adcock System. The Adcock radio range system employs five towers and two transmitters. This makes it possible to transmit voice and range signals at the same time. One transmitter, whose output is not keyed, is connected to the fifth (center) tower. From it transmission is continuous and may be voice-modulated whenever desired.

The other transmitter is connected to the four outside towers and sends out a carrier frequency 1,020 cycles above the carrier frequency of the center tower. This carrier is keyed with the A and N signals, as in the 4-tower system. In the receiver, the signals from the center tower and the outside towers beat against each other to produce the 1,020-cycle note. Thus, the A, the N, and the on-course signals heard in the headsets are identical with those of the 4-tower system.

Whenever there is voice transmission on the Adcock system, however, voice and tone can be heard at the same time. A filter controlled by a 3-posiiton filter switch may be used by the pilot to receive the range or voice signals separately for greater clarity. Preceding every voice transmission, a warning signal is sent for one second to notify the pilot that voice transmission is to follow.

Reception of Range Signals. Any receiver that can be tuned to the frequency of the radio range stations can receive the range signals. For the most dependable reception of range signals, the receiver should not be operated with automatic volume control nor with the continuous-wave oscillator on. The low-frequency band of the radio compass receiver was designed especially for the reception of the range signals.

Marker Beacons. Most radio range stations are located at or near landing fields and serve as reference points for approaches to the fields. It is important, therefore, that the location of the radio range station be unmistakably indicated. Although the cone of silence helps mark the station, there are sometimes other points along the airway where there is fading of the signal which might be mistaken for the cone of silence. Thus, it is desirable to have some positive identification. The station location marker (Z marker) serves this purpose.

The *Z* marker is a 75-megacycle (vhf) transmitter that sends an unkeyed signal vertically into the cone of silence. It has an output of about 5 watts. The carrier is modulated by a 3,000-cycle note which causes a light on the pilot's instrument to flash when the airplane is over the station. The area over which this marker signal is received will vary with the altitude of the airplane and the sensitivity of the marker beacon receiver.

Transmitters similar to the Z markers, operating on the same frequency with the same modulation, are located along the radio range courses, 10 to 35 miles from the station. The output of these transmitters is about 100 watts. They help to determine the location of an airplane and are valuable in traffic control. These transmitters are called *fan markers*.

The fan markers are keyed by dashes according to the number of the course, clockwise from true north. Thus, the fan marker on the first course clockwise from true north is keyed by a single dash and the one on the next course by two dashes. The keyed fan marker signals are also picked up by the marker beacon receiver.

As mentioned previously, all necessary information concerning radio range facilities throughout the United States and adjacent parts of Canada are contained in the publication entitled *Radio Facility Charts*. The publication is designed for use in preparation for flights, and a copy is kept in the airplane at all times. It consists mainly of charts covering the radio facilities in the United States and parts of Canada.

Although basic principles remain the same, continual improvement is being made in present avigational equipment, with the aim of further increasing its dependability and accuracy. Considerable emphasis is being placed on the development of reliable blind landing systems, such as loran, ground control approach, and the instrument landing system. Also, a radically new type of radio range system has been developed which operates in the vhf range. It is now being tested and may eventually replace the present low-frequency radio range system. It is known as visual omnidirectional range.

5. Terminology

Our introduction to air navigation would not be complete without understanding the following terminology commonly used in avigation:

Homing is flying an airplane toward a radio station by following the radio signal from that station. The station may be any range or commercial broadcast transmitter, or it may be a transmitter in another aircraft or a radio installation at any Air Force, Army, or Navy base.

Position-finding simply means that the navigator determines where the aircraft is located at any particular time during flight. The position of an aircraft can be determined by obtaining a bearing on two or three radio stations.

A *bearing* is the direction of some object (radio station) from the aircraft. A bearing is measured in degrees clockwise from some reference line, which determines the type of bearing obtained.

If the lengthwise axis of the aircraft is taken as the reference line, the bearing obtained is called the *relative bearing* (aircraft-to-station bearing). Thus, if the angle between the aircraft's axis and the line to the station is 40°, the relative bearing is 40°.

The angle the axis of the aircraft makes with the line of true north is the true heading. Adding the true heading to the relative bearing will give the *true bearing* (the angle between the line of true north at the aircraft and the line from the aircraft to the station). To find the true bearing requires the use of both the magnetic compass and the radio compass.

If the line of true north *at the station* is taken as the reference line, the bearing obtained is called the *reciprocal bearing*. The reciprocal bearing is measured in degrees clockwise from the line of true north at the station to the line from the station to the airplane. To find the reciprocal bearing from the true bearing, add 180° if the true bearing is less than 180° and subtract 180° if the true bearing is more than 180°.

When the radio compass is tuned to a radio station, the indicator pointer will point to the station. If on a chart a line is drawn to the station in the direction indicated by the pointer, the aircraft must be on that line. A line so drawn is called a *line of position* (LOP), for the position of the aircraft is somewhere on this line. This is repeated for two other stations and their LOP's also drawn on the chart. Because of the distance traveled by the aircraft during the time it takes to tune to three stations, the three lines will form a small triangle and establish the position of the aircraft within the triangle. The smaller the triangle, or the less the time required in tuning to the stations, the more accurate the position finding. This procedure is called obtaining a *fix*. If it takes less than two minutes to obtain the three bearings or if the aircraft travels less than five miles while the bearings are obtained, the fix is called an *instantaneous fix*.

It is very easy to home or obtain a fix with a properly operating radio compass receiver.

Summary

Air navigation is used to determine the position of an aircraft, the time at which it will reach a given position, and the way it must be headed to reach a desired position.

The magnetic compass is the basic navigation instrument and must be corrected for variation, which is the difference between true north and the direction that an undisturbed compass points, and deviation, which is the difference between the direction indicated by an undisturbed compass and that indicated by a particular compass. Another source of error is dip, which is the vertical component of the earth's magnetic field.

The radio compass gives the position of the aircraft. A loop antenna and a sense antenna are used together to obtain the direction of the station.

Air navigation systems include loop and tower antenna systems, the Adcock system, and marker beacons. Many new methods of electronic navigation are also being developed.

REVIEW QUESTIONS

The following questions are study aids. Your answers are not to be submitted to the USAF Extension Course Institute for grading. Correct answers will be found at the end of this text.

1. Define *heading.* How is it measured?
2. What is the difference between true heading and magnetic heading?
3. What two corrections must be made in the magnetic compass so that it will give the actual true heading of an aircraft?
4. What is the difference between compass heading and magnetic heading?
5. How is the compass corrected for easterly deviation?
6. With the compass corrected for deviation, how would you obtain the true heading if the aeronautical chart of the territory showed a westerly variation?
7. What is the compass rose?
8. Give four ways in which an aircraft's position may be determined.
9. Upon what does the operation of the radio compass mainly depend?
10. At the null point, what is the physical relation of the loop with respect to the direction of the radio wave?
11. Why is the null point of loop reception used in the radio compass?
12. Why is the phase of the resultant loop voltage shifted 180° when the loop is rotated past a null point?
13. What are radio range stations and what are they used for?
14. What are the bisignal zones?
15. What is the cone of silence?
16. What is the advantage of the Adcock system over the 4-tower range system?
17. How does the pilot know that he is over the radio range station?
18. What are *Radio Facility Charts?* How are they used?

RADIO COMPASS AN/ARN–7

THE RADIO COMPASS is so called because of its ability to determine the direction from which radio signals originate. The set is basically a very sensitive and stable superheterodyne receiver. Associated with this receiver is a highly directive, rotatable loop antenna and a nondirectional vertical sense antenna. These two antennas, when properly connected into the receiver with the necessary control and power circuits for their operation, result in a very flexible direction-determining system.

In chapter 1 you were given an introduction to air navigational principles and to some of the equipment used for navigating, including the radio compass. It is the purpose of this chapter to teach you how the set performs to produce the conditions which allow its use as an avigational instrument.

You will begin your study with a description of the various units that make up the complete radio set, AN/ARN–7. This will be followed by an analysis of the circuits involved in each of three types of operation.

First, the radio compass can be used as an ordinary receiver (*antenna operation*), with only the sense antenna connected, for reception of modulated signals from broadcast stations, radio range stations, or any other station the set can tune in.

Secondly, by changing the selector (function) switch, you obtain *loop operation*. The receiver is now a sensitive homing device, because the directive loop antenna is substituted for the sense antenna. The loop may be rotated right or left to find the aural-null (no sound) point, which is used for homing.

The loop position is also used for reception of signals during bad weather when there is too much static on the other two types of operation. This is made possible by the electrostatic shielding of the loop housing. If, however, the loop is in null position when flying on a radio range course, the signal may fade in and out and possibly be mistaken for a cone of silence. Therefore, strong stable stations must be selected and tuned in very carefully. It is usually best under such conditions to tune with the loop set at its maximum position to be sure of hearing the station; then, after identification, turn the loop to the null position.

Lastly, the set is operated in *compass* position. In this position, both the loop and the sense antennas are used. The loop is automatically rotated to the null position by the loop-control circuits when a station is tuned in. Two indicators, operated electrically, show the direction of the loop reception. Regardless of the aircraft's heading, the indicator continually points to the station tuned in. It is this last feature that makes the set so valuable to the pilot by continually and instantly indicating to him the slightest change from a predetermined course.

6. General Description

Follow the description of the various circuits by referring to the schematic diagram of the AN/ARN–7 (Chart C–258–A, parts 1 and 2), which is supplied as a supplementary item. Simplified schematic diagrams will be given in the text when it will make the understanding of a particular circuit easier. The JAN or commerical tube numbers corresponding to the VT numbers in the schematic are shown in table 1.

TABLE 1

TUBE COMPLEMENT OF AN/ARN–7

Reference No.	JAN (Commercial) No.
VT–66	6F6
VT–74	5Z4
VT–86	6K7
VT–87	6L7
VT–93	6B8
VT–94	6J5
VT–96	6N7
VT–105	6SC7
VT–109	2051

At this point, data pertaining to the performance characteristics of this set may be of interest. The receiver has greatest sensitivity on antenna position and requires about 3 to 5 microvolts of

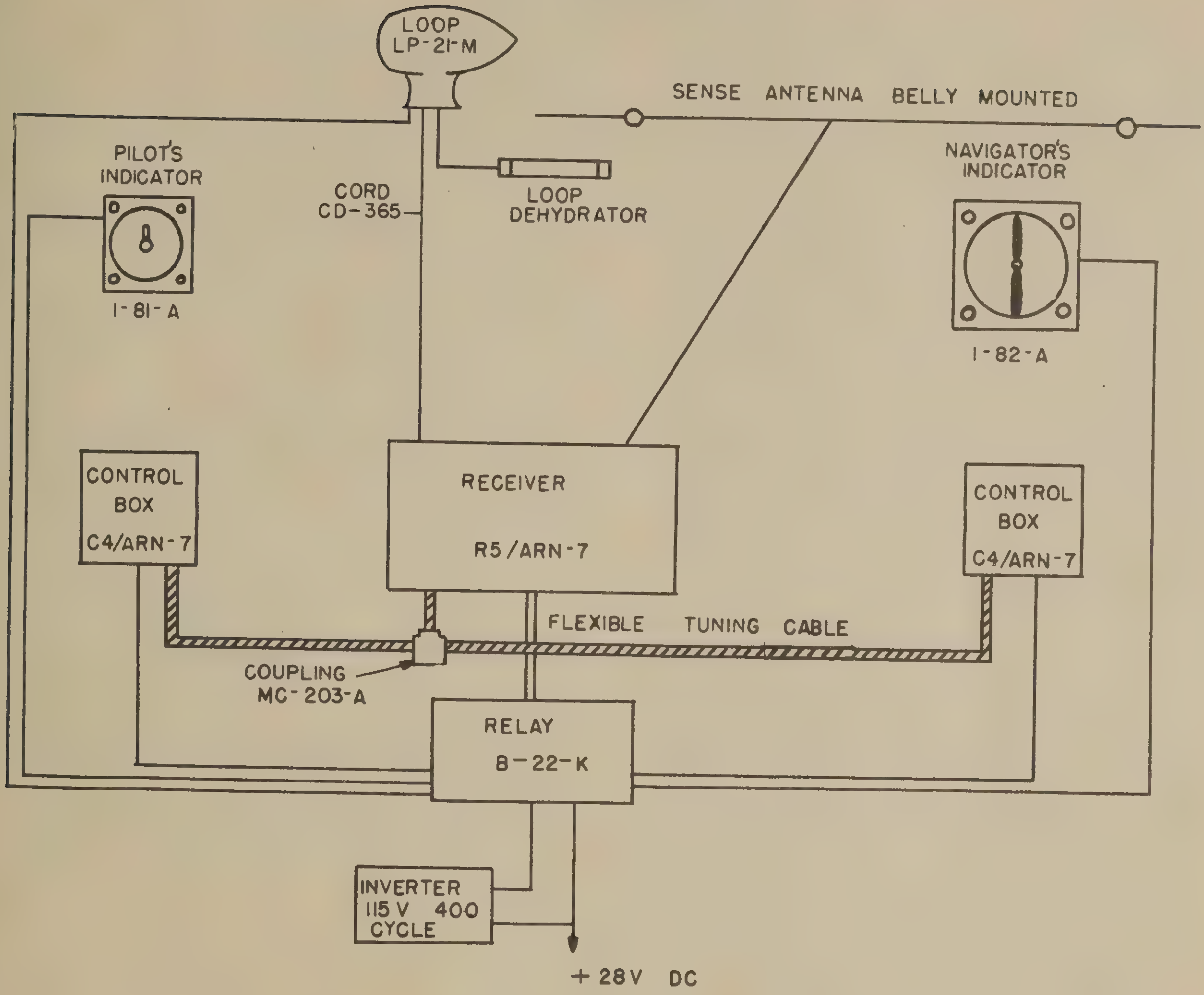


FIGURE 12. Electrical and Mechanical Connections of the AN/ARN-7.

standard input (rf modulated 30 percent at 400 cycles) to obtain the standard output (50 milliwatts signal and voice—noise output not more than 12.5 milliwatts) and is fairly constant on all bands. The selectivity at ten times the normal input is 7.5 kc (bandwidth) at a test frequency of 840 kc and decreases as the frequency increases. The image rejection ratio is better than 1,000:1.

The noise level is fairly constant on all bands on *antenna* position, whereas with loop operation the noise level generally decreases as the receiver is tuned to the higher frequencies. The loop sensitivity is much lower, however, requiring from about 100 microvolts at the lowest frequency to about 30 microvolts at the highest frequency to obtain standard output (varies considerably in different sets).

On automatic compass position, the inherent bearing accuracy is within ±2.5°. Speed of taking bearings is from 4 to 7 seconds for 175° (44° to 25° per second) for field strengths of 100 v to 100 mv per meter. At the same field strength, loop hunting (vibration) can be limited from 0° to ±0.5°.

Before proceeding to the more detailed discussion of the circuits, study figure 12 which shows the electrical and mechanical connections of the set, and figures 13 and 14 which show the top and bottom views of the receiver chassis. Next, carefully study figure 15, the complete block diagram of the radio compass receiver. Note which stages are used in each position of the function switch. Lastly, locate the same stages in the schematic diagram.

Locate plug PL–122—notice that each line going into the receiver is lettered and the corresponding line that goes to a junction-box terminal is numbered. To indicate that the lettered

lines go into a common cable or cord, they are drawn at a slant in the schematic, and the point where they leave the cable for a particular circuit is indicated by the same letter. Similarly, the numbered lines at PL–122 end at the junction-box terminals with the same number. The same system is followed for the connecting lines between the junction box and the control boxes.

The radio compass consists of the following major units (see fig. 16): receiver unit R–5/ARN–7; two remote radio control boxes, C–4/ARN–7; a pilot's indicator, I–81A; a navigator's indicator, I–82A; relay BK–22, and loop unit LP–21LM. In addition, the complete setup requires the necessary interconnecting cords and plugs, the tuning shaft, a nondirectional antenna, mountings for the major units, headphones, and a dehydrator unit.

7. The Receiver

The compass unit, R–5/ARN–7, includes a cabinet (about 19 x 12 x 8 inches), chassis, and mounting. The unit contains all the parts for the superheterodyne receiver circuits, the loop amplifying and phasing circuits, the compass synchronizing and automatic control circuits, the power-supply circuits, the power control relay circuits, and the band-change motor circuits. The unit weighs about 50 pounds.

Power Supplies. The radio compass is designed to operate from two primary power supplies, rated at 24 to 28 volts dc and 115 volts, 400 cycles ac. The dc is obtained directly from the aircraft's central power system (CPS), and the ac is furnished by an inverter. (An inverter is a dc motor and an ac generator combined in one machine. It obtains dc power from the CPS and converts it into 400-cycle, 115-volt ac power.)

Tube Complement and Front Panel. The set contains a total of 15 tubes. Eight tubes are required for antenna operation, two additional tubes are required for loop operation, and the remaining five tubes are required for automatic compass operation.

Since the set is remotely controlled from either one of two remote-control boxes, the front panel of the receiver (see fig. 17) contains only the following items: a plate with adjustment instructions, a loop-sensitivity control, a ground terminal, a release for removing the chassis from the case, a tuning-shaft connection (left center), loop plug PL–108, the sense-antenna terminal, and the multicontact male plug, PL–122, to which all power and control lines of the set are connected.

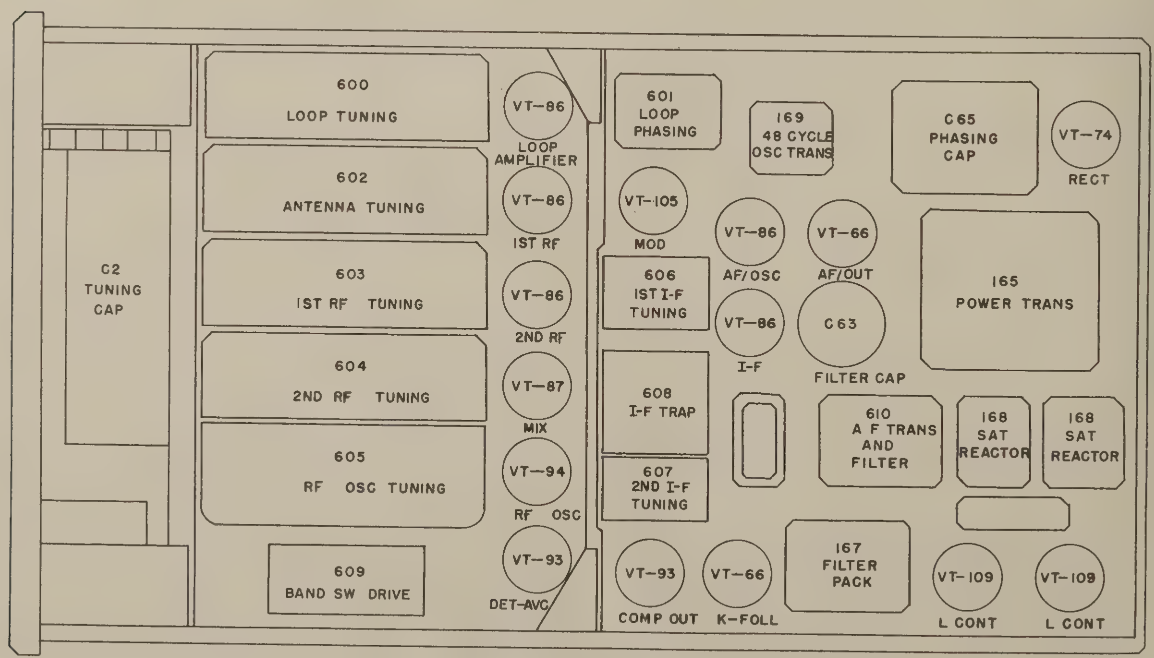


FIGURE 13. Layout Diagram of Top View of R–5/ARN–7 Chassis.

The set is connected to its mounting base through four rubber shock absorbers. The physical appearance of the R–5/ARN–7 is clearly shown in the top and bottom views of the set, figures 18 and 19, respectively.

Frequency Range. The equipment has a frequency range of 100 kc to 1,750 kc covered in four bands as follows: 100 to 200 kc, 200 to 410 kc, 410 to 850 kc, and 850 to 1,750 kc.

8. Remote-control Box

The control box, C–4/ARN–7, provides complete control of the radio compass AN/ARN–7. (See fig. 20.) For dual operation, two identical control boxes are installed in the aircraft. Then either operator (pilot or navigator) can get control of the equipment by pressing the control switch. Only one control box at a time can have control of the equipment. (*Note:* In studying the following description of the control box, refer to figures 20 and 21 and to the schematic diagram.)

Function Switch. The function switch is a 4-position, 2-section, wafer-type switch. In the schematic, it is designated by numbers from *S*35A through *S*35G. To simplify the tracing of circuits in the schematic, *S*35 is shown as seven separate switches ganged together (sections *A, B, C, D, E, F,* and *G*). It is used to turn the set on and to select the type of operation.

Tuning Meter. The tuning indicator, I–70B, is located electrically in the cathode circuit of the second detector stage and is used to give an indication of signal strength. The meter is a reversed-reading dc milliammeter; that is, at zero signal, the pointer is at the left side of the scale and the meter is drawing full-scale current of 5 milliamperes. When a radio station is tuned in properly, the meter pointer shows a maximum deflection to the right, and the meter draws about 2 ma of current. (A more detailed explanation will be given later in this chapter.)

Tuning Crank. The tuning crank operates the dial of the radio control box. It is connected to the ganged tuning capacitor of the receiver through a flexible tuning cable, a coupling, and a train of gears. The gear ratio between the crank and the tuning shaft is 2:1.

Tuning Dial. A radial disk-type dial is used and is calibrated every 5 kc from 100 to 410 kc. A mark with the word *align* is placed at the low-frequency end of the dial on the 850-to-1,750-kc band for alining the dial when the tuning shaft is connected to the radio compass unit, R–5/ARN–7.

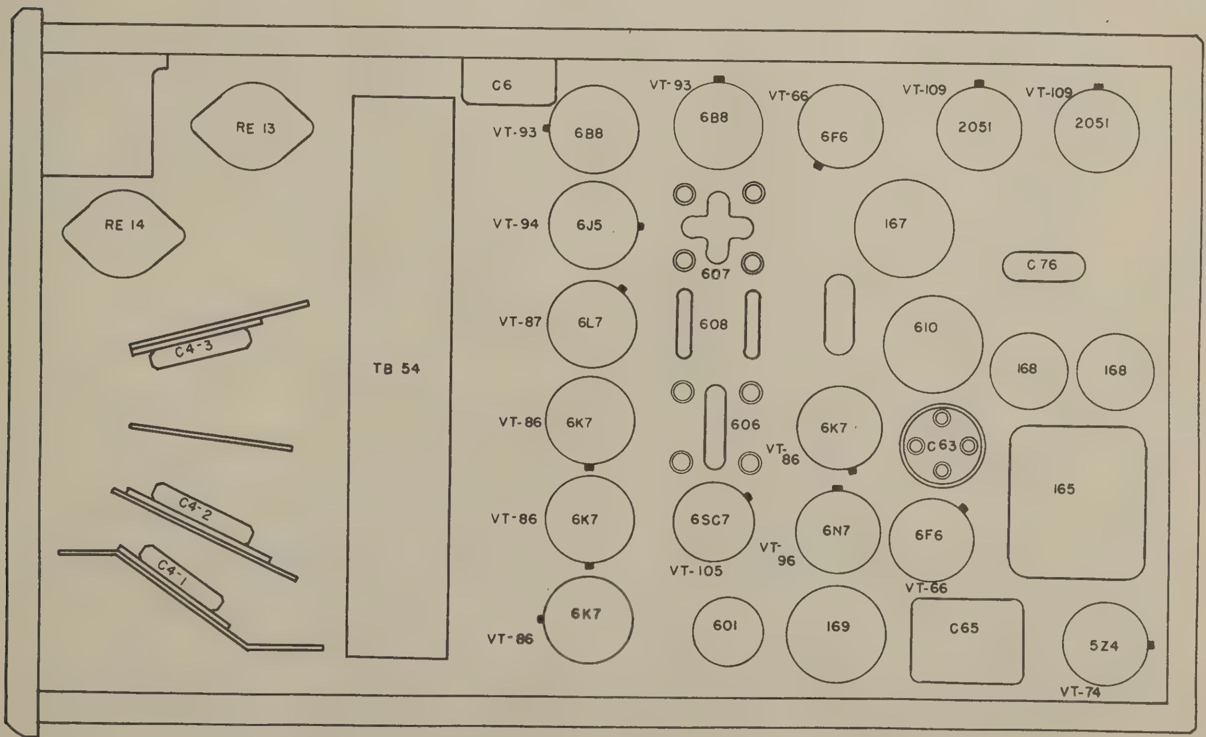


FIGURE 14. Layout Diagram of Bottom View of R–5/ARN–7 Chassis.

Band-change Switch. The band-change switch, *S*34, is a rotary-type, 4-position, 6-contact switch. It selects any one of four bands by energizing the band-change motor. A mask attached to the shaft allows only that part of the tuning dial to be seen which is associated with the band selected. The band range in use is marked on the mask.

Loop Left-right Switch. The loop left-right (L-R) switch, *S*13, is used to rotate the loop in the desired direction during loop operation of the radio compass by completing the electrical circuit of the loop-drive motor.

Audio Control. The audio control knob is used to regulate the level of the audio signal in the headset. The control (*R*79A, *R*79B) consists of two variable resistors mounted on one shaft. *R*79A is used as a potentiometer across the output of the audio stage on compass operation. It has a maximum resistance value of 5,000 ohms. *R*79B is used during the other two types of operation, but it operates as an rf gain control and thereby indirectly controls the audio output.

Control Switch. The control switch, *S*17, energizes the power-input relay and the switching relay of BK–22, thus transferring control from one position to the other.

The CW-voice Switch. The cw-voice switch, *S*36, when closed, energizes a relay which applies an 800-cycle audiofrequency voltage to the suppressor-grid circuit of the i-f amplifier for reception of continuous-wave signals.

Pilot Lights. As you can observe in figure 20, the control box also contains three pilot lights (LM–32). The two lights near the top corners are for illumination of the dials, while the green pilot light in the lower center lights only when that control box has control. The dial-light intensity may be varied by rheostat *R*46.

Headphone Jack and Socket Assembly. The tuning-shaft connection and the headset jack, *J*3, are mounted on one side.

All lines in the control box are completed to a 20-pin plug (19 contacts and 1 guide pin) which fits into its socket (224) in the mounting (see fig. 21). The lines from the socket end at a terminal strip located in the center of the mounting. From the terminal strip, the 19 lines are cabled to corresponding fixed terminals of the junction-box

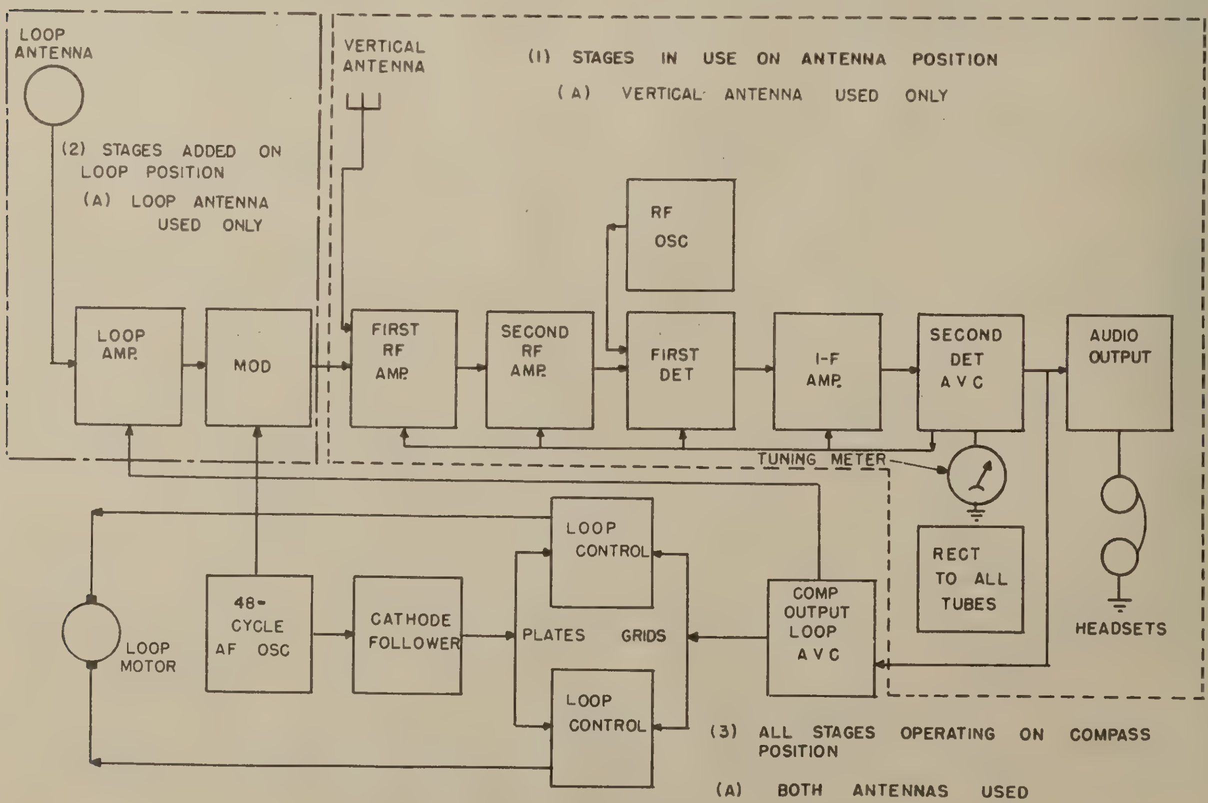


FIGURE 15. Block Diagram of Receiver R–5/ARN–7.

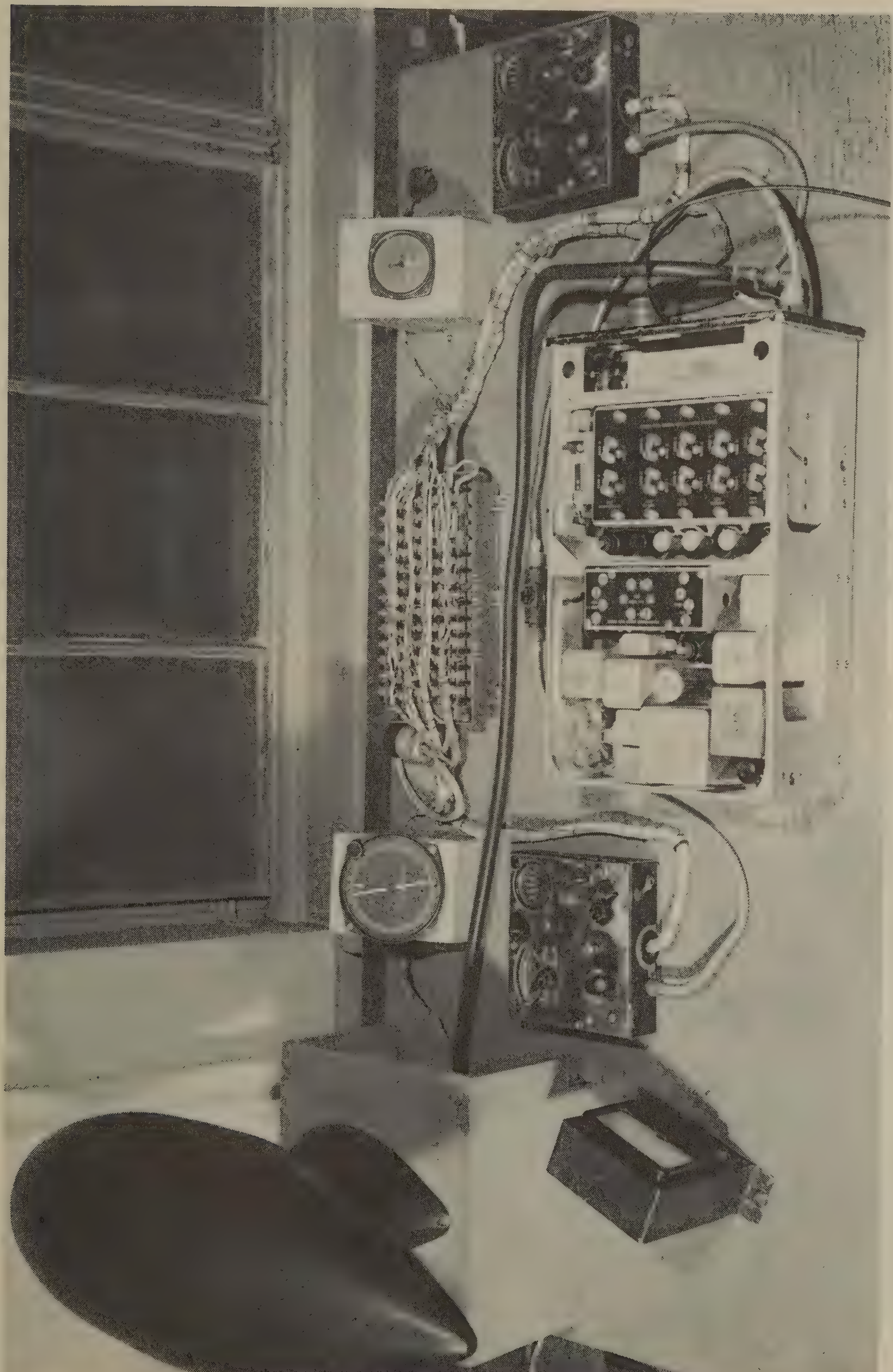


FIGURE 16. Laboratory Setup of Complete Operating AN/ARN–7 Installation.

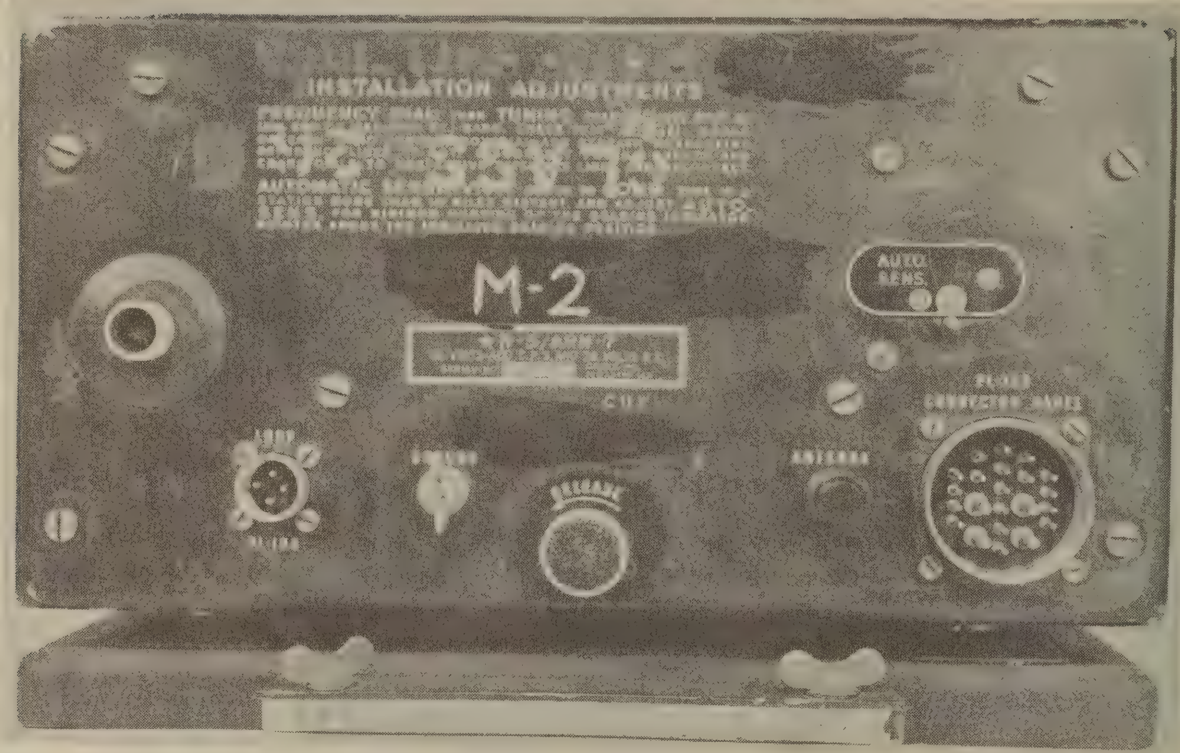


FIGURE 17. Front View of R–5/ARN–7.

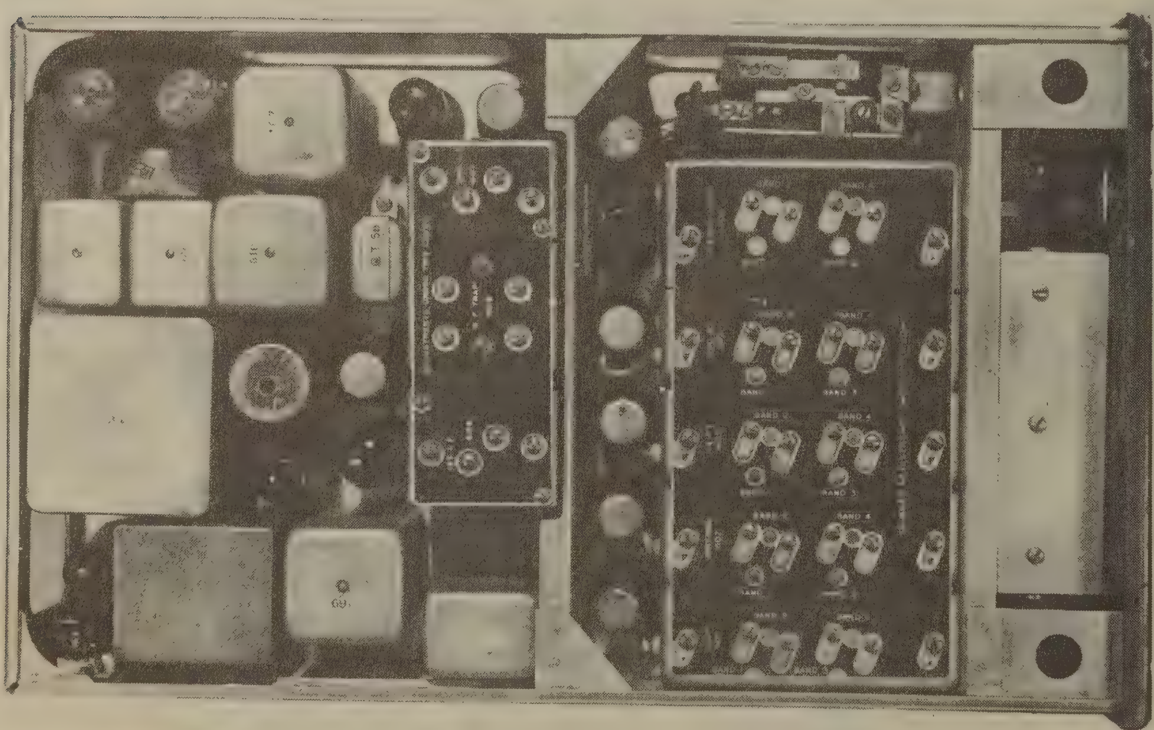


FIGURE 18. Top View of R–5/ARN–7 with Cover Removed.

relay, BK–22K. (This is easily seen in the schematic diagram.)

9. Junction-box Relay

The common power connection for all components is the junction-box relay, BK–22K. (See figs. 22 and 23 and Chart C–258–A.) the 115-volt, 400-cycle ac is connected to terminals 50 and 48, and the 24–28-volt dc is connected to terminals 61 ($A+$) and 24 ($A-$). A 5-amp dc fuse is located between terminals 61 and 60, and a 3-amp ac fuse is connected between terminals 50 and 49.

Power-input Relay. The power-input relay, RE–8, must be energized before any power can be supplied to the receiver unit. RE–8 is a double-pole, single-throw switch operated by a 12-volt, 67-ohm coil, which is energized by the function switch.

Relay BK–22K is a ten-pole, double-throw switch whose sliding contacts are operated by a ratchet assembly (unit 590 in the schematic) using a 28-volt solenoid. Relay BK–22K is energized whenever the control switch *S*17 is pressed. It is used to transfer control from one box to the other.

In single remote-control installations, the junction-box relay is replaced by relay switch *S*172A for 28-volt operation. Unit 580 (shown by dashed lines in the schematic) may be installed as an impedance-matching autotransformer for coupling low-impedance headsets into the high-impedance compass output circuits.

Junction Box. The lines from the fixed terminals of the junction-box relay are cabled and terminate in the 22-contact female plug, PL–122, which fits into the corresponding pin plug, PL–122, in the receiver unit connector panel. The circuits of the indicators (I–81A and I–82A), the loop-drive motor, MO–18A, and the Autosyn transmitter motor, MO–40, are also completed through the junction box. The junction box thus serves as a connector panel for electrical interconnection between the various units.

Resistor *R*150 in series with the RE–8 coil is a 65-ohm voltage-dropping resistor, since the RE–8 coil requires only 12 volts. *R*151 in the ratchet relay assembly is a solenoid-holding resistor, and *C*50 is a filter capacitor.

(*Note:* In the schematic, BK–22K sliding contacts are shown in the position that gives control to the navigator's control box. Since, however, the pilot's control box is more conveniently located in the schematic, we shall assume in further discussion that it has control. Therefore, the sliding

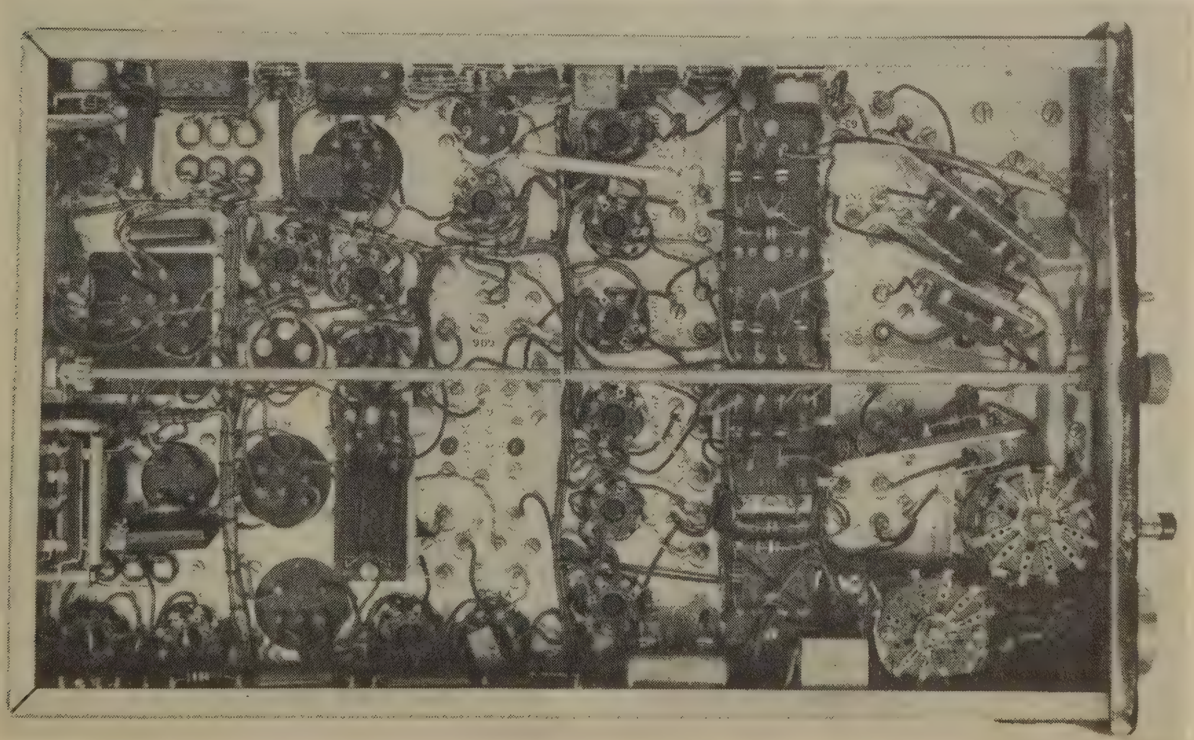


FIGURE 19. Bottom View of R–5/ARN–7 with Cover Removed.

contacts make connection between terminals 16 to 25, to which they are permanently connected, and 3 to 12.)

10. Loop

The loop LP–21–LM includes a graphite-impregnated fiber zeppelin housing containing a loop antenna, the loop-drive motor, the compensator unit, and an Autosyn transmitter motor. (See figs. 24 and 25.) The motors and compensator are located in the base of the housing.

Loop Antenna. The loop antenna consists of an electrostatically shielded 8-turn coil with its center tap grounded. It is mounted on a rotatable shaft driven by a small two-phase induction motor, through a gear train. The loop-drive gear is directly coupled to the compensator unit, which in turn drives the rotor of the Autosyn transmitter and automatically applies the necessary correction for radio compass deviation. (*Autosyn* is a trade name for the small ac machines used in the loop remote indicator system. *Synchros* is the universal term for such devices.)

The Autosyn transmitter or generator, MO–40, operates with single-phase input to the rotor, which energizes the stator field coils (Y-connected) by magnetic induction. The two plugs, PL–108 and PL–112, are located in the base of the loop assembly.

FIGURE 20. Front of Radio Control Box C–4/ARN–7.

Dehydrator. A dehydrator unit is attached to prevent moisture from entering the loop housing. It consists of a plastic tube filled with silica gel mixed with cobalt chloride (blue color). When the gel has absorbed enough moisture to saturate it, the cobalt turns pink. To be reactivated, the gel must be heated in an oven. The dehydrator is connected to the loop housing through a rubber hose.

11. Indicators

With the exception of the calibrated scales and their physical size, indicators I–81A and I–82A are identical. (See figs. 26 and 27.) The indicators show, in degrees, the direction of loop reception; that is, they point directly to the transmitting station tuned in, regardless of the position of the aircraft. The pointers are rotated by Autosyn receivers or motors, MO–16, which are electrically controlled by the Autosyn transmitter MO–40. Together, they comprise a remote indicating or "synchro" system.

Operation and Construction. The indicator pointer is attached to the rotor of motor MO–16 and rotates in synchronization with the rotor of

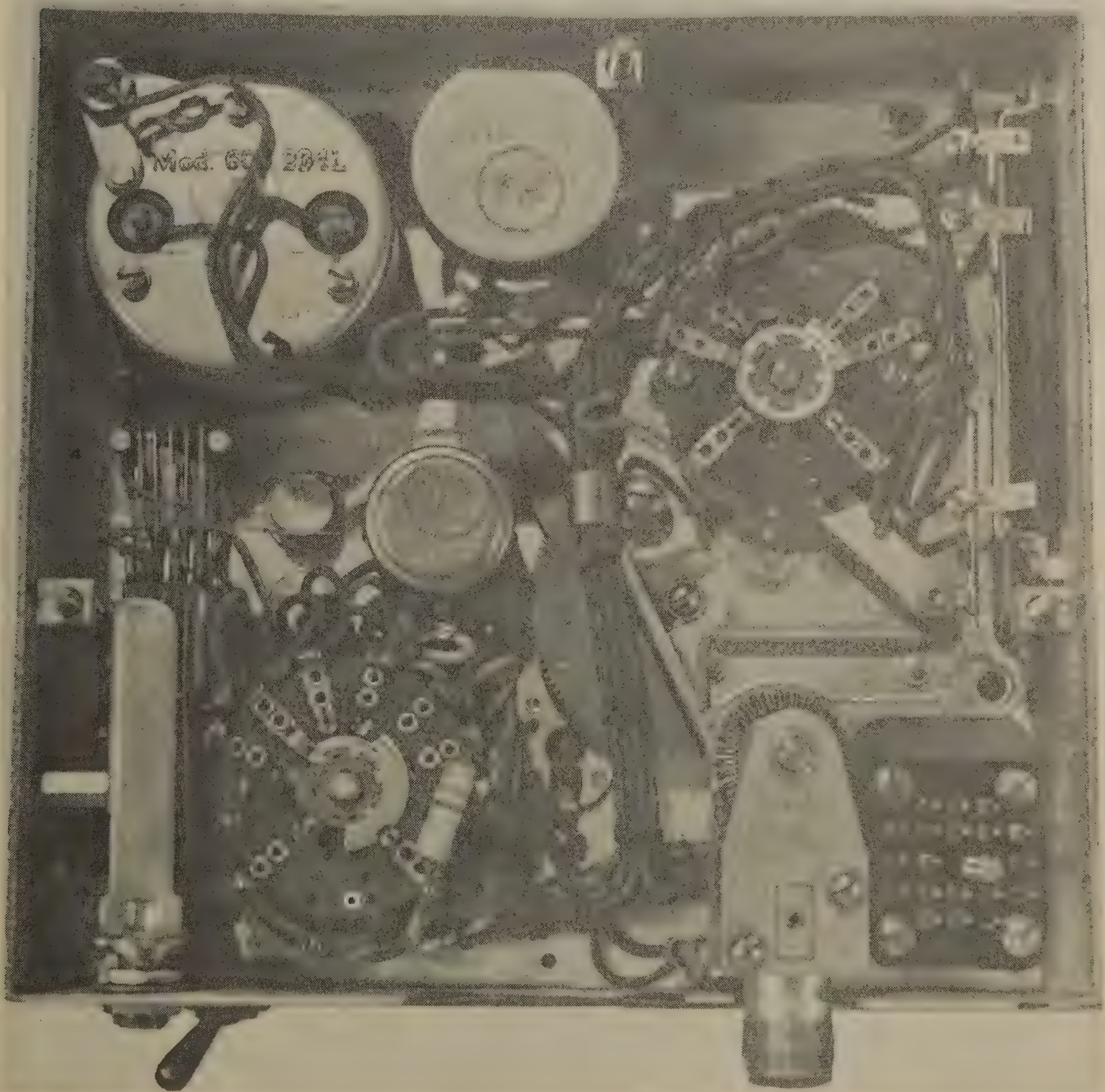


FIGURE 21. Back of Radio Control Box C–4/ARN–7.

generator MO–40, which is geared to the loop as already explained. The motor and generator are very similar in construction. The rotor of MO–40 is controlled by the loop-drive motor, but the rotor MO–16 is free to rotate except for the damping action provided by a flywheel, which prevents oscillation in the motor when the generator stops or starts suddenly. The stator coils are Y-connected like a three-phase ac machine, but the voltages and currents present are single phase, since the rotors are connected to the single-phase 115-volt, 400-cycle source.

The operation of synchros MO–16 and MO–40 is an application of transformer action with the rotor acting as a primary and each stator coil as a secondary. As the rotor turns to different positions, it induces different voltages in each stator coil. These voltages induced in the stator by the

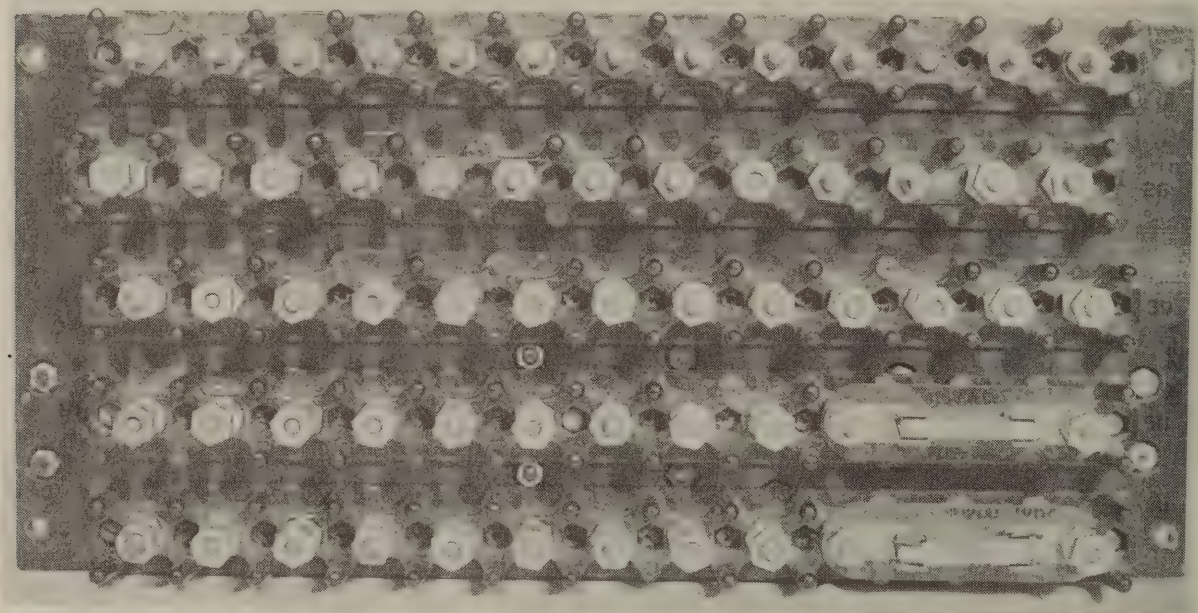


FIGURE 22. Front of Junction-box Relay BK–22K.

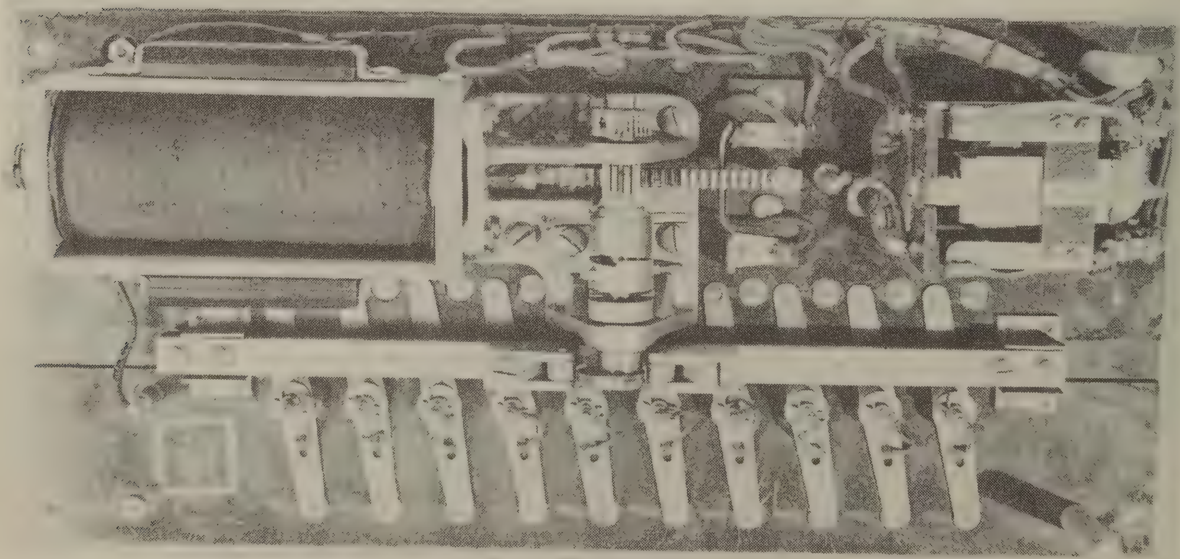


FIGURE 23. Back of Junction-box Relay BK–22K.

generator rotor cause the motor rotor to assume a corresponding position at every instant.

The corresponding terminals of the rotors are connected to the 115-volt source, so that the voltages applied are identical in magnitude, phase, and frequency. Each motor stator lead is likewise connected to its corresponding generator lead. The same ends of the stator coils, therefore, have the same instantaneous polarity; that is, the voltage across corresponding coils of the motor and generator will be in opposition. If both rotors are alined (same relative position), the induced voltages in each pair of corresponding coils will be equal; since they oppose, their resultant terminal voltage is zero. Therefore, no current flows in the stator windings when the two rotors are alined.

When the loop-drive motor has turned the generator rotor so that it is no longer alined with the motor rotor, the stator voltages of the generator (MO–40) are no longer equal to the stator voltages of the motor (MO–16). A potential difference then exists across corresponding coils of the motor and generator, causing currents to flow, which set up flux fields that exert torque on the rotors. Since the generator rotor is held mechanically, only the motor rotor (indicator) is turned by this torque until the positions of the rotors correspond again and the stator voltages are equal.

Calibration of the I–81A. The pilot's indicator scale is graduated in 5° intervals and fixed so that the 0° mark is in line with the index mark, which in turn is in line with the nose and tail of the aircraft.

Calibration of the I–82A. The navigator's indicator scale is graduated in 1° intervals and can be rotated. This is convenient for the navigator

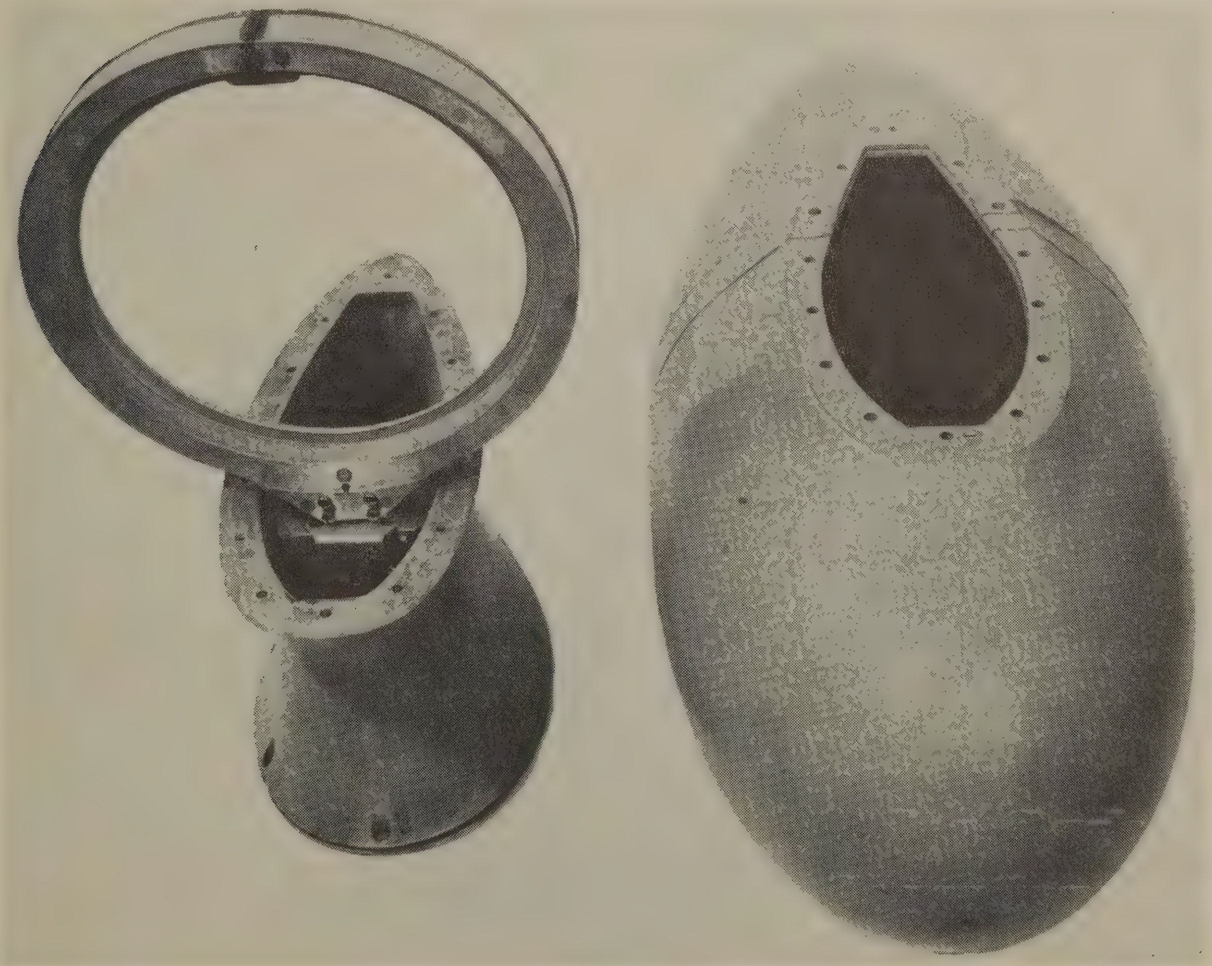


FIGURE 24. Loop LP–21–LM with Housing Removed.

when taking bearings. He can correct for variation and set the zero mark in a line with true north. The fixed index mark would then point to the aircraft's true heading. At the same time, the rotating pointer trained on some transmitting station would then indicate directly the aircraft's true bearing.

12. Primary Circuits for Antenna Operation

This discussion must be studied from the schematic diagram (Chart C–258–A). As previously mentioned, we shall assume that the pilot's control box (C–4/ARN–7) has control. The set is operating on band 1 (position 1 of the band-change switch, *S*34), and the function switch, *S*35 (all sections), is assumed to be in antenna (A) position.

To turn the set on, you simply turn the function switch, *S*35, to the desired position and tune to a particular station by rotating the tuning crank. When the set is properly tuned, the tuning meter, I–70B will give a maximum deflection to the right.

We shall begin our discussion by tracing the circuits controlled by the function switch.

Power-input Relay Circuit. The function-switch section, *S*35A (upper right corner of the pilot's control box), energizes the power-input relay, RE–8, by completing the solenoid circuit to ground. In the schematic, the rotating contact of *S*35A is grounded as follows: from the contact trace downward to the second junction point, then to the left to terminal C of mounting FT–224A.

Line 11 connects to terminal C and emerges as line 11 at the junction-box relay, BK–22K. Through a sliding contact of BK–22K, line 11 is connected to the fixed contact 24 (terminals 24, 25, and 26 of BK–22K are connected together by double lines). From 24, follow the short slanted line into the common cable upward into plug PL–122.

The corresponding terminal 24 makes contact with terminal F (or line F) about 7 inches to the right, where it goes to ground, thus grounding the rotating contact of *S*35A. (Note that lines or electrical conductors are either numbered or lettered the same at both ends. As a careful inspection of the schematic will show, most of the lettered lines from PL–122 enter the common

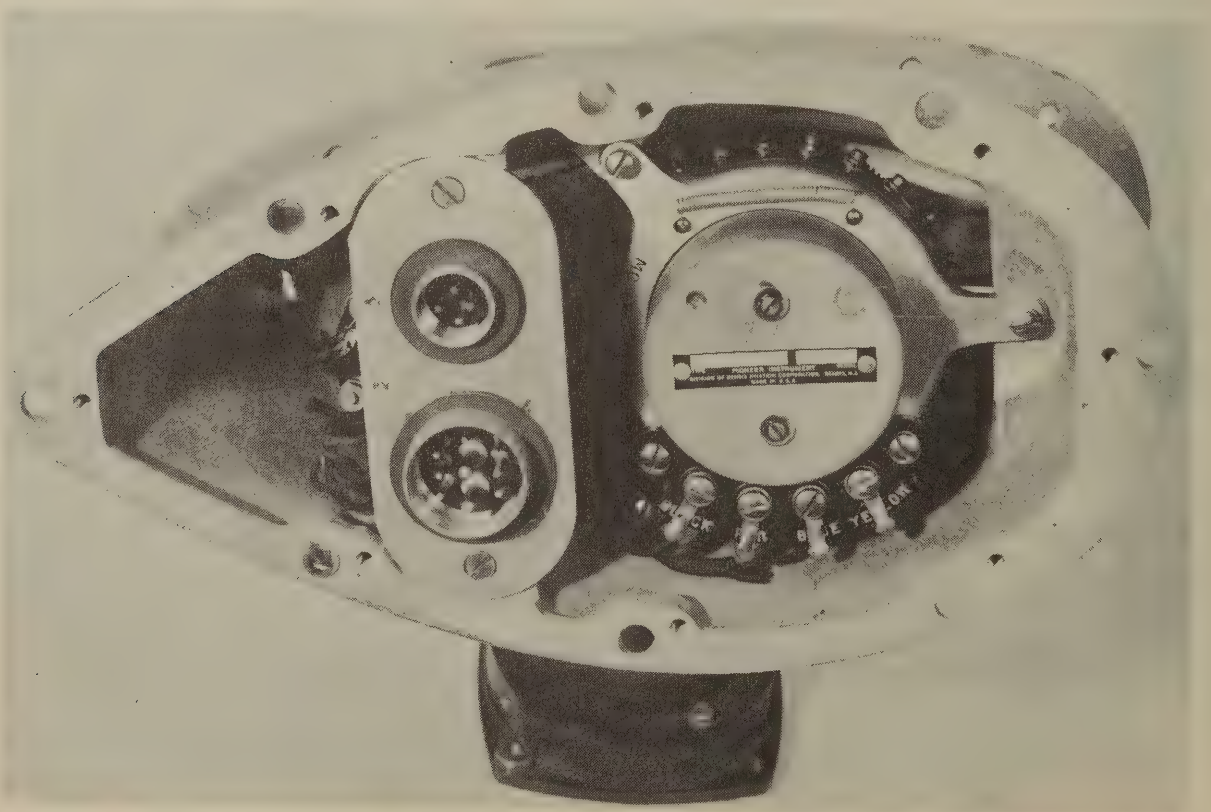


FIGURE 25. Bottom View of Loop LP–21–LM.

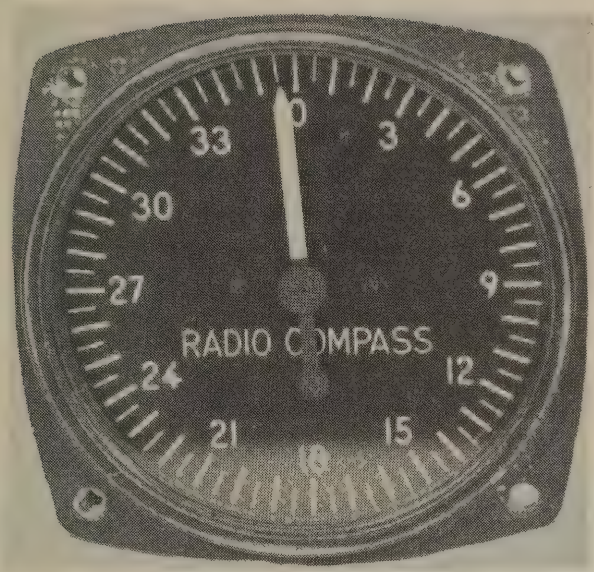


FIGURE 26. Pilot's Indicator I-81-A.

receiver cable at a slant and the point where they leave the cable is indicated by a corresponding letter. Therefore, you can save time by simply looking for the desired letter along the cable and then following the corresponding lead into a particular circuit.)

Returning to *S*35 with the antenna position now grounded, trace to the left to terminal T into line 58. As you enter the junction box, follow the first or bottom line to the left, then upward about two inches, and take the first slanted line to the left, which connects to corresponding terminal 58 and to one side of the power-input relay solenoid (coil), RE-8, thus grounding one side of the solenoid circuit.

To complete the circuit to the *hot* side of the dc source, trace through the coil and *R*150 to positive terminal 60. With RE-8 energized, the primary ac and dc power is applied through the relay contacts and PL-122 to the set.

Primary AC Circuit. The 115-volt, 400-cycle ac line circuit is traced as follows: from 50 of BK-22K (hot side of the line) through the 3-amp fuse to 49, though the bottom relay contact to 56 of BK-22K, then to terminals 56-W of PL-122. (The 56 terminal is the female or socket side of the plug, and W is the male side of plug. In practice, you simply refer to the hot side of the ac line as line 56-W or just line W. Each of the other lines are similarly named, depending upon the circuits they complete.)

Line W branches off the cable and connects to terminal 2 of the primary of power transformer 165 (lower right side of the schematic).

The other side of the winding at terminal 1 connects to line R, which goes back to PL-122 at terminals R-48. The end of this line is at fixed terminal 48 in the junction box. The ac line cord connects, therefore, to terminals 50 and 48 in the junction-box relay unit.

Primary DC Circuit. The 24-28-volt dc line starts at terminal 61 ($A+$), the hot side of the line. Then it goes through the 5-amp fuse to terminal 60 and through the upper contacts of RE-8 to 57 and 27 of the junction box to 27-V in PL-122. It is easily seen that line V ($A+$) branches off to a number of relays. To energize the relays, however, the other side of the solenoids must be connected to ground ($A-$).

Antenna Relay Energizing Circuit. At PL-122, line V enters the cable and also connects to a junction point at RE-13, the antenna relay, located directly above PL-122. Part of the RE-13 coil is shorted out by its *S*38D contact. The momentary large current flow through the coil results in a large starting torque. As soon as the relay is energized, contact *S*38D is opened and the current now flows through the entire coil to keep the relay closed.

In either case, the relay coil circuit is completed to ground through contact *S*37A of the loop relay, RE-14, and contact *S*35D. RE-14 is located in the upper portion of the schematic. This relay is energized only during loop operation. (All relays are shown in the unenergized position in the schematic.) The movable contact of *S*37A connects to terminals T-23 in PL-122. T-23 connects, through a sliding contact of BK-22K, to line 36, which connects to terminal J in the pilot's remote-control box. Line J is taken to ground through section *S*35D of the function switch, completing the antenna relay circuit.

Circuit Functions of Antenna Relay RE-13. The relay consists of four sets of contacts operating as single-pole, double-throw switches. The relay completes circuits in the de-energized position only (as shown in the schematic), and when energized it simply opens those circuits, since the armatures now connect to fixed contacts having no circuit connections.

The circuits completed by each contact are as follows:

S38A. The armature contact connects to the

cathode of the high-voltage rectifier, *VT*–74 (*B*+). The lead from the fixed contact connects to *S*37F contacts of the loop relay, RE–14. From the armature contact of *S*37F of RE–14, trace carefully down and across to the extreme right of the schematic, and you will come to terminal 2 of transformer *T*38, which is the primary winding of the 48-cycle audio oscillator, VT–96 (located at the other end of the schematic). From No. 2 of *T*38, the tracing is continued to the plate and screen of the cathode-follower tube, *VT*–66. Thus, contact *S*38A completes the *B*+ circuit to the cathode follower and the 48-cycle af oscillator stages.

S38B. This contact completes the common ground to the Autosyn circuits, that is, pilot's and navigator's indicators (receivers) and the transmitter motor, MO–40, located in the loop assembly. The movable contact is grounded near terminal 11 of the secondary winding of power transformer 165. The fixed contact completes the ground circuits through C–41 of PL–122 and terminal 41 of BK–22K. (Notice that there is one line leading in the No. 41 and that there are three lines leading out to the three Autosyn

FIGURE 27. Navigator's Indicator I–82–A.

motors. The detailed tracing will be left to you.)

S38C. This contact completes the *B*+ circuit to the loop amplifier, *VT*–86, and the modulator stage, *VT*–105. The movable contact is the *B*+ (hot) side of the circuit. It is connected to the cathode of the high-voltage rectifier (*B*+ source) by way of *L*9 (located directly below the audio output transformer *T*59). Choke *L*9 (5 h) with capacitors *C*60–1 (0.05-μf rf bypass) and *C*63A–1–2 (30-μf filter) forms a capacitor-input pi-type filter for the high-voltage power supply, *VT*–74.

S38D. As previously stated, *S*38D completes the relay solenoid circuit for high starting torque by shorting out part of the coil.

From the above explanation, you should conclude that the antenna relay makes inoperative those circuits which are not needed during antenna operation of the radio compass.

13. Radio-frequency Section of Antenna Operation

Since the receiver circuits are for the most part typical for the particular vacuum tubes used, we shall not give detailed explanations of the function of each part and circuit. Rather, we shall place emphasis on the distinctive features of this set and on the understanding of the circuit schematic as a whole.

We shall begin by an analytical description of the various stages used on ANTENNA position of the function switch in the same order that the signal progresses from the nondirectional (sense) antenna to the headphones in the pilot's (or navigator's) control box. The block diagram (see fig. 15) gives you an over-all picture of the stages used on the ANTENNA position of the function switch; however, the complete schematic (Chart C–258–A) is the *blueprint* from which your studying will be done. For the physical location of stages, refer to figures 13 and 18.

The rf section consists of two rf stages using 6*K*7's, a pentagrid mixer stage (first detector) using a 6*L*7, and the local oscillator stage using a 6J5 tube in a tuned-grid circuit.

Antenna Input Circuit. When the function switch, *S*35, is on ANTENNA position, relay RE–13 is energized and only the sense antenna is used. The antenna connection to the receiver is indicated by "A," which is located at the top of the schematic, 12 inches in from the left side of the chart.

The antenna is connected to the antenna-input tuned circuit which, on band 1 as shown, consists of the secondary coil of *T*44 shunted by trimmer capacitor *C*75–5A. (*Note:* All the antenna tuning circuits for the four bands are inclosed in a shielded can. This unit is labeled No. 602 for reference purposes and includes all parts within the rectangle shown by a broken line in the schematic.) The variable tuning capacitor section, *C*2–2A, completes the antenna tuning unit. It is located at the lower right end of tuning unit 602 and is used on all bands.

The antenna is connected to its tuned circuit through contacts *S*37C of the loop relay RE–14, coupling capacitors *C*17 and *C*107, and section *S*27C of multicontact band-change switch *S*27. Capacitors *C*17 and *C*107 are rated at 500 volts and will prevent damage to the antenna transformer if a high dc voltage is applied to the antenna. A 1-megohm resistor is connected between antenna and ground to allow electrostatic charges to leak off to ground when the antenna is not connected. The antenna circuit is also protected by a voltage-limiting neon bulb, NE 1–1, located at the bottom of antenna tuning unit 602. It ionizes at 65 volts rf and 90 volts dc.

Intermediate-frequency Wave Traps. The i-f wave traps (unit 608) are located between the cathodes of the two rf stages and ground. On band 1 (as shown), the cathode of the first rf stage is connected through switch *S*39A to the parallel resonant tank consisting of *C*114–1 and *L*23, which resonates at 245.5 kc. For the other three bands, coil *L*26 is switched into the circuit and the trap then resonates at 140.5 kc. Similarly, the wave trap in the second rf amplifier resonates at 241.5 kc on band 1 and 144.5 kc on the other three bands.

Switches *S*39A and B, which control these tanks as well as all the band-change switches, are ganged to the band-change motor 621 (located just left of power transformer 165). We shall discuss the motor circuit later in this chapter. Like all parallel resonant circuits, these wave traps offer high impedance to frequencies at or near resonance. The voltage developed across the tanks acts like that across an unbypassed cathode resistor, producing degeneration at the undesired intermediate frequencies and thereby preventing them from being amplified.

The only other circuit components whose function you may question are the resistors used in

the grid-tuned circuits of both the second rf and the mixer stages. They are connected in series between the control grid and its tuned circuit on each band. In the first rf coil assembly (unit 603), they are numbered *R*71–1 (39Ω), *R*5–1 (25Ω), *R*10–1 (10Ω), and *R*9–1 (3Ω). They are called *compensating resistors;* that is, they tend to offset any variation in signal amplitude on the four bands.

Circuit Tracing and Analysis. So that you will have no doubts as to tracing complete tube circuits in this schematic, we shall trace in detail the principal circuits of the *first rf amplifier* as an example.

Control-grid dc circuit. Trace from the grid to a junction point below *C*107, through band-change switch section *S*27C, then up through the top coil (secondary of *T*44 on band 1) tuning unit 602. Then follow the common lead down through *R*14–4 (*R*14–4 = 50,000Ω and *C*4–1 = 0.05μf for the first rf avc filter) into the common avc line. Follow this line past three junction points to the end (about 16½ inches to the right), where it connects to the 1-megohm diode avc filter, *R*18–3.

Proceed through *R*18–3 and through *R*18–2 to ground. *R*18–2 is the diode load resistor, which develops the avc voltage for the first and second rf, the mixer, and the i-f stages. It is also 1 megohm. (Note that nearly all resistors, capacitors, and coils have a double numbering system, for example, *R*18–1, *R*18–2, *C*28–1, *C*28–2. All parts having the same first number are identical. The second number simply locates that part in a particular circuit.)

We have traced the circuit to ground, but the circuit is not completed until we have traced to the cathode of the same tube. (Or we may complete the circuit by starting at the cathode and tracing this part of the circuit to ground, which in this case is the easiest, since there is no obvious ground at the cathode.)

From the cathode of the first rf tube, follow the line down through *S*39A, *L*23, *R*24–1 (600-Ω cathode-bias resistor) to terminals *L*17 of PL–122. Follow line 17 (through the cable) to terminal 17 in junction box BK–22. Through a sliding contact, terminal 17 connects to terminal 4 (pilot's remote-control box in control). Line 4 (through the cable) ends at terminal L in mounting FT–224A of the pilot's remote-control box. In the control box, line L leads to a junction point near *S*35B and to the compass contact (C) of the same switch which is open. (You recall all sections of the function switch *S*35 are on ANTENNA position.)

From the junction point, trace up through the closed contacts of *S*35F down through rf gain control *R*79B. From the center tap of *R*79B, the circuit is completed to ground through the closed contacts of *S*35G. On ANTENNA and LOOP positions, *S*35G is simply a grounding switch, since these contacts connect to line C–11, which connects to the ground terminal 24 in BK–22K.

In tracing the complete dc circuit, we have seen that the rf gain, and therefore the volume or output of the receiver, is controlled by rheostat *R*79B, which is electrically in the cathode-to-ground circuits of the first rf, second rf, and mixer stages. Radio-frequency gain control *R*79B has a value of 35,000 ohms and is the rear section of a dual control. The front section, *R*79A, is a 5,000-ohm potentiometer which is used as an audio volume control on COMPASS position of the function switch. We shall study its associated circuit later in this chapter.

Control-grid signal (rf) circuit. This is the complete ac path between the grid and cathode. The rf currents follow the path of least impedance, which is through the bypass capacitors as follows: from the grid, trace down through tuning capacitor *C*2–2A to ground (or through the associated tank coil and through the avc bypass capacitor, *C*4–1, to ground), then up through the cathode bypass capacitor, *C*28–15, and through *C*114–1 to the cathode, thus completing the circuit.

Plate dc circuit. From the plate of the first rf tube, trace through band-change switch section *S*28–1 and the primary coil of rf transformer *T*48–1. Then trace down to the fourth junction point and to the left to a *B*+ (about 175 volts) terminal. Continue through the plate-dropping resistor, *R*20–2 (5,000Ω), and down to a junction point with lines leading to the right and to RE–13 contacts *S*38C.

Since we must trace to the high-voltage power supply, follow the common *B*+ line to the right entirely across the schematic to a junction point just above rf bypass capacitor *C*60–1. Then follow up through terminal 2 of audio output transformer *T*59 to terminal 7 (215 volts) of audio output unit 610.

Continue tracing to the cathode of the high-voltage rectifier, VT-74. From the cathode, the electrons (current) go to either plate out through the center tap of power transformer 165 and up through *R*74B to ground. (*R*74B is a 50-ohm resistor used to develop bias for loop-control tubes, not a bleeder.)

To complete the plate current circuit to the cathode of the rf amplifier, you must trace from ground No. 24, line 11, in BK-22K, then through the switches and rf gain control *R*79B in the pilot's control box, etc., as was done for the dc grid circuit above. (All tube circuits are traced in a similar manner. Circuit tracing with certainty is a must if a thorough knowledge of any piece of radio equipment is to be obtained.)

Interstage Radio-frequency Coupling. The output of the first rf stage is transformer-coupled into the grid circuit of the second rf stage. The second rf grid circuit is tuned by the second coil of *T*48-1 (band 1) shunted by trimmer *C*75-7A and variable tuning capacitor section *C*2-3A. (Variable capacitor *C*2 consists of five identical ganged sections—1A . . . 5A—with a capacitance range of 400$\mu\mu$f max to 20$\mu\mu$f min.) The second rf stage is practically a duplicate of the first rf stage, including the transformer coupling into the signal-grid circuit of the mixer (first detector) stage, VT-87.

Mixer Stage. The mixer (first detector) stage employs a 6L7 pentagrid tube which is purposely designed to be used with an external rf oscillator. This stage produces the desired i-f in its output plate circuit by combining the signal frequency with the rf (local) oscillator frequency. The signal voltage is applied to the control grid (g_1), and the local oscillator voltage is applied to the injector grid (g_3). The input, output, and oscillator circuits are shielded from one another by the shielding effect of the dual screen grids, resulting in a very stable output.

The i-f switching relay, RE-15, is energized only on band 1 by completing its solenoid circuit to ground through switch *S*33B, located in the band-change motor, assembly 609. This places trimmer *C*98-1A (3 to 17$\mu\mu$f) in shunt with the primary of the first i-f transformer, *T*56-1, and tunes the mixer plate circuit to 243.5 kc. On the other three bands, C74-9A is similarly connected and tunes the mixer plate circuit to 142.5 kc. The mixer stage couples to a similarly tuned circuit which is connected to the control grid of the i-f amplifier.

Local Oscillator. The local oscillator voltage is generated by a triode (6J5) tube connected in a tuned-grid, plate-inductive, feedback circuit. The oscillator grid-leak bias is developed across *R*14-3 (50,000Ω), while *R*14-1 serves the same purpose for the injector-grid circuit of the mixer stage. *C*2-5A and *C*2-4A are used to tune the oscillator and mixer grid circuits, respectively. The oscillator voltage is coupled through *C*25 (15$\mu\mu$f) to the injector-grid circuit. The oscillator operates with a plate voltage of 45 volts as compared with 195 volts for the mixer plate.

Intermediate-frequency Stage. The receiver has one stage of i-f amplification using a 6K7 variable-μ tube with tuned input and output circuits.

Tuning assemblies 606 and 607 contain high-Q, powdered-iron-core i-f transformers *T*56-1 and *T*56-2, respectively, with associated trimmer capacitors and i-f switching contacts operated by RE-15. The i-f switching in the plate circuit is performed by switch *S*32 in the same way that it was by switch *S*31 in the grid circuit.

The tube operates with 170 dc volts on the plate and 140 volts on the screen. On ANTENNA position, as the schematic shows, the i-f amplifier is biased by *R*93 in series with the parallel combination of *R*63-2 (1,000Ω) and *R*49-2 (5,000-Ω variable sensitivity or threshold control), since the circuit is grounded at the junction below the sense control through contacts *S*37B of the relaxed loop relay RE-14.

On LOOP position of the function switch, that is, when the loop relay is energized, contact *S*37B is open. The cathode is now grounded below *R*78, placing *R*64-2 (5,000Ω), *R*49-3 (5,000-Ω loop sensitivity control), and *R*78 (2,000Ω) in the cathode-bias circuit. This additional resistance will increase the bias and decrease the gain of the i-f stage, thereby decreasing the over-all receiver sensitivity on LOOP position. This is done to keep the receiver sensitivity constant for each type of operation (antenna, loop, and compass).

The sensitivity increases to maximum as the variable tap on *R*49-2 is moved to its upper end (in the schematic), thus shorting out the parallel combination and leaving only the minimum bias resistor, *R*93, in the cathode-to-ground circuit. The shunt resistor, *R*63-2, sets the minimum

sensitivity, since its value determines the highest resultant resistance of the two in parallel.

The lower three resistors operate likewise in LOOP position, with the upper three resistors then presenting a resultant fixed resistance in series. The output of the i-f stage is coupled directly from the secondary of $T56$–2 to the diode demodulator (second detector), and from the primary of $T56$–2 it is coupled through $C41$–3 (0.01μf) to the avc diode plate of VT–93 (6B8 duo-diode pentode).

14. Audio Section for Antenna Operation

Two stages are included in the audio section of the receiver: (1) the 6B8 (VT–93), which demodulates the signal, develops the avc bias, and amplifies the audio voltage, and (2) the 6F6 (VT–66) audio output tube, which develops sufficient power to operate several pairs of headsets.

Demodulator (Second Detector). The detector diode (left-hand plate of VT–93) conducts during the positive pulses of the modulated i-f signal. The audio signal voltage is developed across the load resistors $R12$–6 (100kΩ) and $R28$–1 (250 kΩ). Capacitors $C14$ (100$\mu\mu$f) and $C13$–1 (50$\mu\mu$f) provide the rf filtering. $R28$–1 is usually called the *diode load;* it is also, however, the load and signal source for the grid circuit of the first audio section of the 6B8. $C13$–2 and $R12$–1 form an rf isolating filter.

First Audio Amplifier. Since the screen grid is externally connected to the plate, this section of VT–93 operates as a triode audio voltage amplifier with about 190 volts on the plate. The audio voltage across the plate load $R60$ (33kΩ) is capacitively coupled through $C28$–12 (0.1μf) to the grid of VT–66. Capacitor $C28$–12 and grid load resistor $R33$ form a high-impedance rejection circuit to the 48-cycle loop-control voltage.

Diode AVC Circuit. The second diode plate of VT–93 is used in a delayed avc circuit. This plate is capacitively coupled to the plate circuit of the i-f amplifier through $C41$–3 (15$\mu\mu$f). On bands 2, 3, and 4, this capacitor is paralleled by $C91$ (100$\mu\mu$f) through i-f switch section $S32$C. The diode will conduct and develop a bias voltage across the avc load resistor, $R18$–2 (1 megohm), whenever the i-f signal voltage exceeds the fixed bias (delay) voltage of about 3 volts, which is developed across $R91$ (12kΩ). $C4$–6 (0.05μf) is the cathode bypass, and $C28$–31 (0.1 μf) filters the rf from the tuning-meter lead (line A).

The avc bias is applied to the first and second rf amplifiers, the mixer, and the i-f amplifier. On strong carrier signals, the bias on the grids of these variable-mu tubes will be increased, thereby decreasing their gain. This action tends to keep the incoming signals at a constant level.

Tuning-meter Circuit and Operation. The tuning meter, I–70B, located in the control box, is connected in series with the cathode lead of VT–93 (second detector, first af, avc tube), and its operation is dependent upon the change in plate current through the first af section of this tube. The no-signal cathode current of 5 ma produces full-scale deflection to the left (no station tuned in). A decrease in cathode current resulting from increased carrier voltage at the signal diode causes the meter to deflect to the right.

When the receiver is properly tuned to a station, the meter current is about 2 ma, causing a maximum deflection to the right. The cathode current through the first af plate circuit is reduced as a signal is tuned in, because the control grid of the tube is connected directly to the negative side of the diode load resistor. Therefore, as the pulsating dc voltage across the diode load increases, the average value of the pulsations will increase.

This voltage appears as an increase in bias on the grid, which reduces the plate or total cathode current through the tube and causes the tuning meter to deflect. $R83$ is a 350-kΩ bleeder resistor connected from the $B+$ side of the power supply to ground through the tuning-meter circuit.

The complete dc plate circuit for the first af section of VT–93 is traced as follows: from the plate through $R60$ and $L9$ (5-henry filter choke) to the cathode of VT–74, then through the rectifier tube, the high-voltge secondary, and center tap to ground through $R74$B.

To complete the rest of the circuit from ground to the cathode, trace from the cathode to ground as follows: from the cathode through $R91$ into line A, which contacts line 21 at PL–122, then to terminal 21 in BK–22K, which connects to line 8 through the relay sliding armature contact. Line 8 connects to terminal A in mounting FT–224A, and this leads directly through the tuning meter to ground. ($R65$–2 is a 600-Ω meter shunt. The dc resistance of the meter movement is 5 ohms.)

Audio Output Stage. The 6F6 audio output tube is a typical audio power stage whose output is transformer-coupled to the headphone jack (*J*3) in the control boxes. The primary of *T*59 is shunted by capacitor *C*99, which bypasses any frequency above 3,000 cycles. Thus, the frequency response of the transformer is limited to speech frequencies from about 300 to about 3,000 cycles.

The transformer, *T*59, has the following design characteristics: impedance—primary 5,250 ohms for the high-impedance tap (terminal 5 and ground) and 150 ohms for the low-impedance tap (terminal 4 and ground); turns ratio P to S = 2.3:1, P to S tap = 5.93:1; resistance—primary of 185 ohms, secondary of 51 ohms. The primary is rated at a maximum dc of 350 milliamperes and an rms voltage of 1,500 volts.

The tube-socket voltages are plate, 209 v; screen, 214 v; cathode bias, 13 v. The audio is taken directly to either control box by line B–1. (Terminal 1 in BK–22K serves simply as a junction between the two lines involved.) Line B in the pilot's control box continues through *S*35C (ANTENNA position) to the tip in the headphone jack, *J*3.

From the secondary tap of audio output transformer *T*59, a degenerative feedback voltage is capacitively coupled through *C*28–6 to the grid circuit of the first audio amplifier tube, VT–93, at the junction of *R*12–6 and *R*28–1. Resistor *R*72 (820kΩ) in the feedback circuit acts as a decoupling resistor. This feedback voltage reduces distortion and improves the load characteristics of the audio stage.

15. High-voltage Power Supply

The 5Z4 high-voltage rectifier, VT–74, develops about 215 volts dc for the plates and screens of the amplifier tubes. Its output is filtered by a pi-type filter consisting of two 30-μf, 350-v electrolytic capacitors (*C*63A–1 and *C*63A2) and a 5-henry filter choke, *L*9. Capacitor *C*60–1 is an oil-filled 0.05-μf rf bypass connected across the electrolytic capacitors to filter any rf voltage that may be built up across them.

The power transformer is of special design having a 115-volt, 400-cycle primary and five separate secondary windings. Starting with the high-voltage secondary winding, which is connected to the *VT*–74 plates as No. 1 secondary, and proceeding consecutively to the fifth, the purpose of each winding is as follows (all voltages rms):

1. Develops 426 volts plate-to-plate for the 5Z4 rectifier tube, VT–74.
2. Develops 5.2 volts for the rectifier heater.
3. Develops 48.5 volts for the Autosyn motors and from terminal 10 to ground; 28 volts is developed for the low-impedance winding of the loop-drive motor. *R*74B (50Ω) located between terminal 9 and line Q is a current-limiting resistor.
4. Is the 6.3-volt heater winding for the various amplifier tubes.
5. Develops 62 volts each side of its center tap for the high-impedance winding of the loop-drive motor. Capacitors *C*28–29 and *C*28–30 (0.01μf) are rf line filters in the ac power lines (W and R).

16. Band-change Circuits

Since the band-change motor and associated switches may be operated through the band-change switch, *S*34, at the control box on any position of the function switch, *S*35, we shall conclude our study of the antenna operation of the radio compass with a discussion of the band-change circuits.

Bands are changed by switching the tuned circuits in the loop, antenna, first rf, second rf, and local oscillator stages by means of motor-driven switches. Switch *S*33, sections A and B (located in the band-switch motor assembly 609), and the rf band switches are ganged on one drive shaft. When the band-selector switch, *S*34, is operated to select a different band (say, from band 1 to band 2), the ratchet motor is energized by completing the circuit to ground.

To trace the circuit in detail from *S*34 in the pilot's control box, the moving contact of this switch is grounded at terminal 25 in BK–22K through line V–12. Setting the switch to band 2 grounds line D–42, which leads directly to a tie point in the junction box and then to 42–D at PL–122. Line D ends at terminal 4, which connects to one side of the ratchet motor coil (621) through the shorting switch, *S*33A; the other end of the coil is connected through a *hash* line filter (assembly 611) to the +28-volt line, V. The motor operates until the slot in the moving contact of *S*33A opens the circuit at the band 2 fixed contact.

The so-called ratchet motor is actually a

vibrator-type device (no armature) which consists of a large solenoid, 621, and a ratchet mechanism. (The ratchet is a notched wheel with a pawl that allows movement in only one direction.) Switch *S*40 makes and breaks the circuit to cause movement of the ratchet mechanism.

A spark suppressor (components *C*97, *R*5–3, *C*44–3) is used at the vibrating switch *S*40 to prevent arcing. During the band-change operation, the noise-silencing relay, RE–6, is also energized. This grounds the audio line during the motor operation, preventing noise in the headphones.

17. Loop Operation

In this section, we shall explain how the receiver becomes a 10-tube superheterodyne using a manually controlled loop antenna when the function switch is set on LOOP position.

With the function switch *S*35 in LOOP position, the antenna relay (RE–13) becomes de-energized and the loop relay (RE–14) becomes energized. The vertical antenna is disconnected from the first rf stage, and the loop antenna is now in use. The loop amplifier stage, VT–86, and half of the modulator stage, VT–105, are placed in operation as additional preamplifier stages. The left-right (L-R) switch (*S*13) on the control boxes is connected into the loop-motor control circuit. Having noted the changes made for loop operation, we shall now proceed to analyze the electrical circuits involved.

Function Switch. All the circuit changes are made directly or indirectly through this switch. You can easily see that the functions of switch sections *S*35A, *S*35F, *S*35G, and *S*35C are the same on ANTENNA and LOOP positions, since their respective contacts are connected to the same lead. To review briefly, *S*35A energizes the power-input relay, RE–8; *S*35F with *S*35G completes the rf gain-control line to ground; *S*35C completes the audio line to headphone jack *J*3. Actually, therefore, only two switch sections (*S*35D and *S*35E) are responsible for the circuit changes made from ANTENNA to LOOP positions, since the antenna second loop contacts of *S*35B have no connections.

*S*35D de-energizes antenna relay RE–13 by opening the ground side of the circuit and now energizes the loop relay RE–14 by completing its solenoid circuit to ground, line P–18 at PL–122. Notice that contact *S*37G of RE–14 momentarily shorts part of the solenoid winding to provide a high starting torque and is opened when RE–14 is energized.

*S*35E simply completes a ground to the loop L-R switch, *S*13. The ground is made through the energized contact *S*37A of the loop relay. (In tracing the ground line from the control box through BK–22K, PL–122, etc., note that line T–23 is completed to the loop relay contact through the relaxed contact, *S*38D, of the antenna relay, RE–13.)

Relay Contacts Pertinent to Loop Operation. In RE–13, the only contact remaining that is necessary to loop operation is *S*38C, which applies *B*+ to the loop amplifier and modulator tubes.

In the energized loop relay (armature contacts shifted to the right in the schematic) the following contacts are involved:

*S*37A grounds loop L-R switch.

*S*37B opens the ground connection between the two sensitivity controls of the i-f cathode circuit, thereby increasing the cathode resistance. This reduces the gain of the i-f amplifier for loop operation, but tends to equalize the over-all gain of the receiver for each type of operation. *S*37B also places an antenna compensating capacitor, *C*90–3, across the antenna input circuit.

*S*37C disconnects the vertical antenna from the receiver input and shorts it to ground.

*S*37D removes ground from the modulator cathode to convert one section of this stage into an rf amplifier. (To avoid repetition, we shall analyze this stage when compass operation of the set is explained.)

*S*37E opens the ground line to the saturable reactors (168).

*S*37F opens the *B*+ line to the cathode follower (*VT*–66) and the 48-cycle oscillator (VT–96).

Loop Amplifier Stages. The signal from the loop antenna is transformer-coupled into the grid circuit of the loop amplifier, which is a typical rf stage. The bias for this stage is obtained from the bias circuit of the loop-control tubes (two *VT*–109's located at the upper right-hand corner of the schematic). The dc grid circuit of the loop amplifier, VT–86, is traced as follows: from the grid through the secondary of *T*40 and down through the decoupling resistors *R*12–4 and *R*18–4 into the avc line; follow the avc line across the schematic which leads up to a de-

coupling resistor $R28$–2, then through $R28$–2, $R49$ (autosensitivity control), and $R74B$ (50-Ω bias resistor) to ground.

Since the cathode of the loop-amplifier tube is grounded directly, the dc grid circuit is completed. The actual bias developed depends upon the resultant resistance of $R74B$, $R57$, and the setting of $R49$. To the rectified current from the power supply (VT–74), $R74B$ is in parallel with $R49$ (5,000Ω) and $R57$ (2,500Ω), so that the bias voltage is the same across either branch. A screwdriver adjustment is provided at the receiver front panel for adjusting the center tap on $R49$ to change the bias.

The grid circuit of this stage is protected from damage from any high antenna voltages by the neon bulb, NE–1–2, which ionizes at about 65 volts ac. $C2$–1A is used as the tuning capacitor in the grid circuit for all bands. The parallel tank ($L22$, $C21$) in the plate circuit resonates at 40 kc. Since the lowest frequency the receiver will tune is 100 kc, the tank is highly capacitive; that is, the phase of the signal voltage is made to lag the current by about 90°. This shifting of the signal is important only on automatic compass operation and will be explained later.

The output of the loop amplifier is capacitively coupled through $C19$–2 to the grid circuit of the second loop rf stage (top half of modulator tube VT–105). In the plate circuit, the signal is transformer-coupled ($T44$, band 1) into the first rf stage. The two additional loop-amplifier stages are needed because the signal picked up by the loop antenna is weak compared with the signal of the sense antenna.

From the first rf stage, the signal is handled through the superheterodyne receiver circuits as explained for antenna operation.

18. Controls for Loop Operation

Manual Control of the Loop-drive Motor. The loop-drive motor, MO–18A, is a split-phase (2-phase ac), capacitor-type, induction motor which requires that its two field coils be excited by currents of the same frequency but 90° out of phase. The electromotive force is supplied by separate secondary windings of power transformer 165. The motor's low-impedance (low-Z) winding is supplied with 28-volt ac from terminal 10 of the third secondary winding (from the top). The high-impedance (high-Z) winding is connected to the center tap terminal 7 of the fifth secondary. There is 62 volts between the center tap (No. 7) and each end (No. 6 and No. 8) of secondary No. 5.

In the schematic, the low-Z winding is drawn in the horizontal position and connected to motor socket pins 4 and 2; the remaining upright winding is, of course, the high-Z winding. The low-Z winding is continually connected to its ac source (28 volts) through a phasing capacitor, $C65A$ (located near the power-supply filter, $C60$–1), which causes the current to lead the voltage by about 90°.

The circuit is traced from the ground side (pin 4) of the low-Z winding (motor socket pin No. 4 is grounded through contacts $S38B$ of RE–13 line C–41 at PL–122), through the winding into line 39, which connects to line X at PL–122. Follow line X through $C65A$ to terminal 10 of the low-Z secondary, then through the windings to ground, completing the circuit.

The hot side of the high-Z winding is connected to the center tap of the 62-v secondary at terminal 7. Terminal 6 or 8 of this winding is grounded through the loop left-right switch, $S13$, depending on whether the loop is to be rotated to the left or to the right. The L-R switch, $S13$, is simply a current-reversing switch. The center fixed contact is grounded, as previously mentioned, through $S35E$. The series resistor, $R74B$, limits the current value through the switch.

The switch can be operated in two ways to cause either a slow or a fast rotation of the loop motor. For slow rotation the switch is simply turned in the desired direction (right or left), and for fast rotation the switch is first pressed and then turned. At the switch, for slow rotation to the left, the outer left spring contact makes contact with the inner spring contact, closing the circuit to ground. The circuit is traced from ground through $S35E$, $R47B$, $R47A$ (limits the current, causing slow rotation), and the two left contacts of $S13$ to line S–28. From PL–122, line 28–H completes the ground side of the circuit at terminal 6 of the 62-v secondary.

The hot side of the circuit is traced from the center tap (terminal 7) of the 62-v secondary directly into line U, which connects to line 43 at PL–122. Line 43 ends at socket pin 2 of the high-Z winding. The other end of the high-Z winding is grounded at terminal 25 in BK–22K. (The complete circuit for right rotation is traced in like manner.)

The only circuit change for fast rotation is that $R47A$ is shorted out by the inner spring contact, which now makes contact with the center fixed contact. The resulting increased current causes faster rotation of the motor. The current through the high-Z winding, depending upon its direction, will either lead or lag the current through the low-Z winding, which is the required condition for operating this type of induction motor. In addition to the ac required, the high-Z winding also has a small dc constantly applied to it from the 28-v primary source. A current-limiting resistor, $R74A$ (25Ω), and a filter choke, $L20$ (part of oscillator transformer unit 169), are placed in series in this dc line.

The hot sides of the dc and ac sources are connected to the common junction for line U, which leads to the high-Z winding; thus, the source voltages are applied in parallel. The direct current polarizes the winding; that is, it makes the high-Z coil an electromagnet of sufficient strength to prevent the motor armature, and therefore the antenna, from moving or oscillating when not desired.

Miscellaneous Controls. You have been shown the circuit function of the various controls in the remote-control box as they were logically needed. We shall now explain the electrical functions of the three remaining controls, namely, control switch $S17$, rheostat $R46$, and cw-voice switch $S36$. These switches function independently of the type of operation selected.

Control Switch. The top contact of switch $S17$ completes the primary low-voltage circuit to ground for solenoid 594 of the ratchet relay unit in BK–22K. This changes control from one control box to the other. The lower contact grounds the movable contact of $S35A$ for the control box not in control, thus energizing RE–8. The push-button switch must be held down long enough (a few seconds) for the mechanical ratchet to complete its cycle.

Rheostat. The rheostat, $R46$, is connected in series with one side (No. 12) of the 6.3-volt heater winding of the power transformer and two of the pilot lights. The rheostat can be used to dim the lights as desired. Note that the lights are connected across half of the 6.3-volt winding and that all the vacuum-tube heaters are connected across the entire winding. The remaining light, not controlled by $R46$, is the green light that indicates which box has control.

The CW-voice Switch. The primary 28-volt circuit to ground, for the cw relay, RE–12, is completed by the cw-voice switch. The closed relay contact connects the 800-cycle ripple frequency from the center tap of the high-voltage secondary through the coupling capacitor, $C28$–11, to the cw transformer, $T58$. The tuned secondary of transformer $T58$ is connected directly to the suppressor grid of the i-f amplifier tube. Therefore, the carrier will be modulated and the 800-cycle tone will be heard in the headsets. Continuous-wave operation can be used to tune the set sharply as well as for code reception.

19. Compass Operation

In the section on loop operation, you were shown how the loop antenna was rotated to the right or left when the high-impedance winding of the loop-drive motor was energized by the manually operated loop L–R switch. It remains to be shown, then, how the same thing is done automatically to keep the loop antenna at its null position regardless of the aircraft's heading.

Because the radio compass is actually an automatic left-right direction-finder and because the basic principles of all such devices are similar, we shall begin with the study of analogous functional circuits before proceeding to the specific circuits of the set. You must keep in mind that the proper operation of these circuits depends upon the phase relation of the resultant loop and sense-antenna signals, combined with a synchronizing voltage.

Mechanical Switching System. The basic principle of operation of the radio compass can be explained by referring to figure 28. In this illustration, the loop and sense antennas are connected to the same receiver.

The loop connection is made through a reversing switch. For either position of the switch, the outputs of the two antennas are combined to produce the usual cardioid response curve (see fig. 29). When the loop connections are alternately reversed by the switch, the direction of flow of the loop current is reversed and this, in turn, causes the cardioid pattern to be reversed (see fig. 30).

In this basic system, a center-zero meter having two opposed windings is connected to the rectified output of the receiver, and the connections to the meter are reversed as the loop switch is

changed by a synchronized switching arrangement. In the *A* position of the switch the meter pointer will deflect in one direction, and in the *B* position in the opposite direction. The amount of deflection is proportional to the output of the receiver for each connection of the loop.

In practice, the switch is reversed at a rate too fast for the meter to respond to the fluctuating receiver output. It instead deflects a distance proportional to the difference between the receiver outputs for the two loop connections.

Figure 31 shows the cardioid response patterns (loop and sense voltages combined) for four different positions of the loop antenna and the resultant voltage applied to the receiver. Detail A shows the on-course response patterns, which correspond to the null position of the loop antenna. The receiver outputs are equal regardless of the position of the switch, and the pointer remains at its center-scale position.

The signal voltage applied to the receiver is represented by vector b for one position of the switch and by vector a for the other position. The meter deflects a distance proportional to the difference of the receiver outputs for the two positions of the loop reversing switch, which in this case is zero ($b - a$ or $a - b = 0$). Detail B shows that the loop is turned to the right of true null, so that voltage b due to cardioid M is the greater. Therefore, the meter deflects to the left a distance proportional to $b - a$. (*Note:* In this system, the meter points in the direction the pilot must turn the aircraft to get on course.)

The position of the response patterns in detail C indicates the loop is facing to the left of true null. The meter, therefore, deflects to the right, a distance proportional to $a - b$.

In detail D, the loop antenna has rotated 180° from the position indicated by detail B. The cardioid response patterns are reversed. Thus, the receiver output corresponding to voltage a is greater than the output corresponding to voltage b and the pointer deflects to the right, a distance proportional to $a - b$. (The 180° rotation reversed the "sense" of the direction finder.) The back or false-null side of the loop is facing the transmitter. The pilot would know he was flying away from the transmitter because the meter would point in the same direction that the loop is turned, indicating reversed sense or the reciprocal bearing.

Electronic Switching Systems. In actual direction-finding circuits, the reversing of the loops is usually done electronically instead of mechanically. A functional diagram of a basic electronic switching circuit is shown in figure 32. The loop signal is applied to the grids of tubes V_1 and V_2, which are connected to opposite ends of the center-tapped secondary of the input transformer. Thus, the loop voltages appearing on the grids are 180° out of phase.

The grids of the input tubes are also connected to the output of a push-pull square-wave audio oscillator. The strength of the square-wave voltage is sufficient alternately to cut off the plate current of tubes V_1 and V_2. Thus, the loop

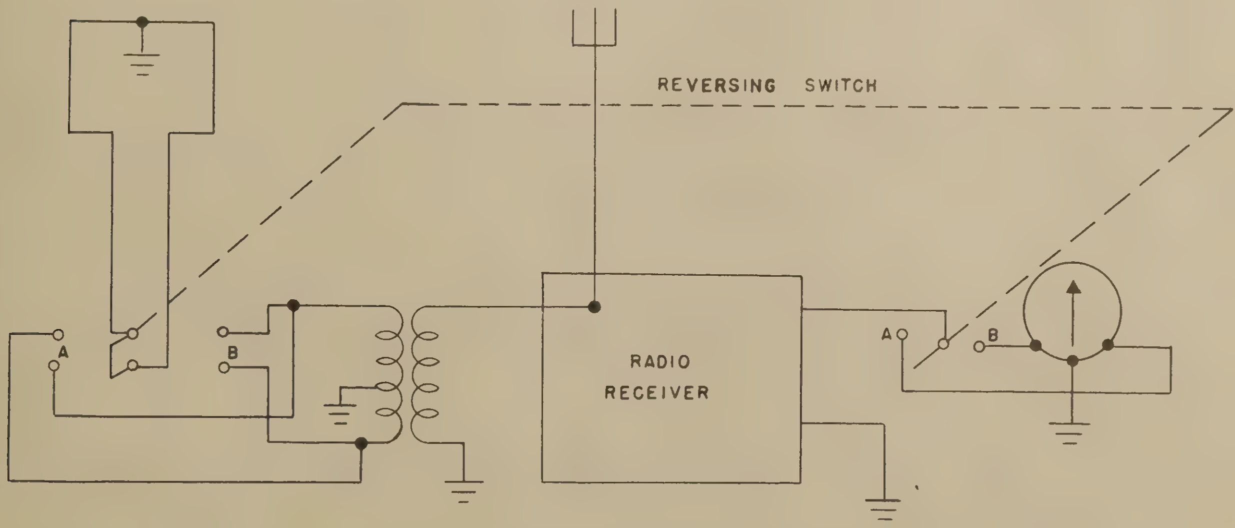


FIGURE 28. Mechanical Switching System.

rf voltages which are 180° out of phase are alternately fed to the input of the radio receiver, where they are combined with the voltage from the sense antenna.

The loop voltage will add and subtract from the sense-antenna voltage to produce the two cardioid patterns shown in figure 31. The rectified output of the receiver is a combination of dc plus audio voltage having a frequency equal to that of the square-wave oscillator and an amplitude proportional to the combined voltages of the loop and sense antennas.

The receiver output is fed to a synchronous rectifier consisting of tubes V_3 and V_4. The grids of these tubes are also connected to the square-wave oscillator. Thus, V_1 and V_3 grids are negative at the same time and are driven to cutoff, while V_2 and V_4 operate as amplifiers and rectifiers in the normal manner. On the next alternation of the audio oscillator, the opposite takes place; that is, V_2 and V_4 are cut off, while V_1 and V_3 operate normally.

The output voltage across the load resistor of V_3 is proportional to the loop voltage across V_1 and the sense-antenna voltage. Similarly, the output voltage across the load resistor of V_4 is the resultant of the loop voltage output of V_2 and the sense voltage. The meter cannot respond fast enough, however, to measure the individual

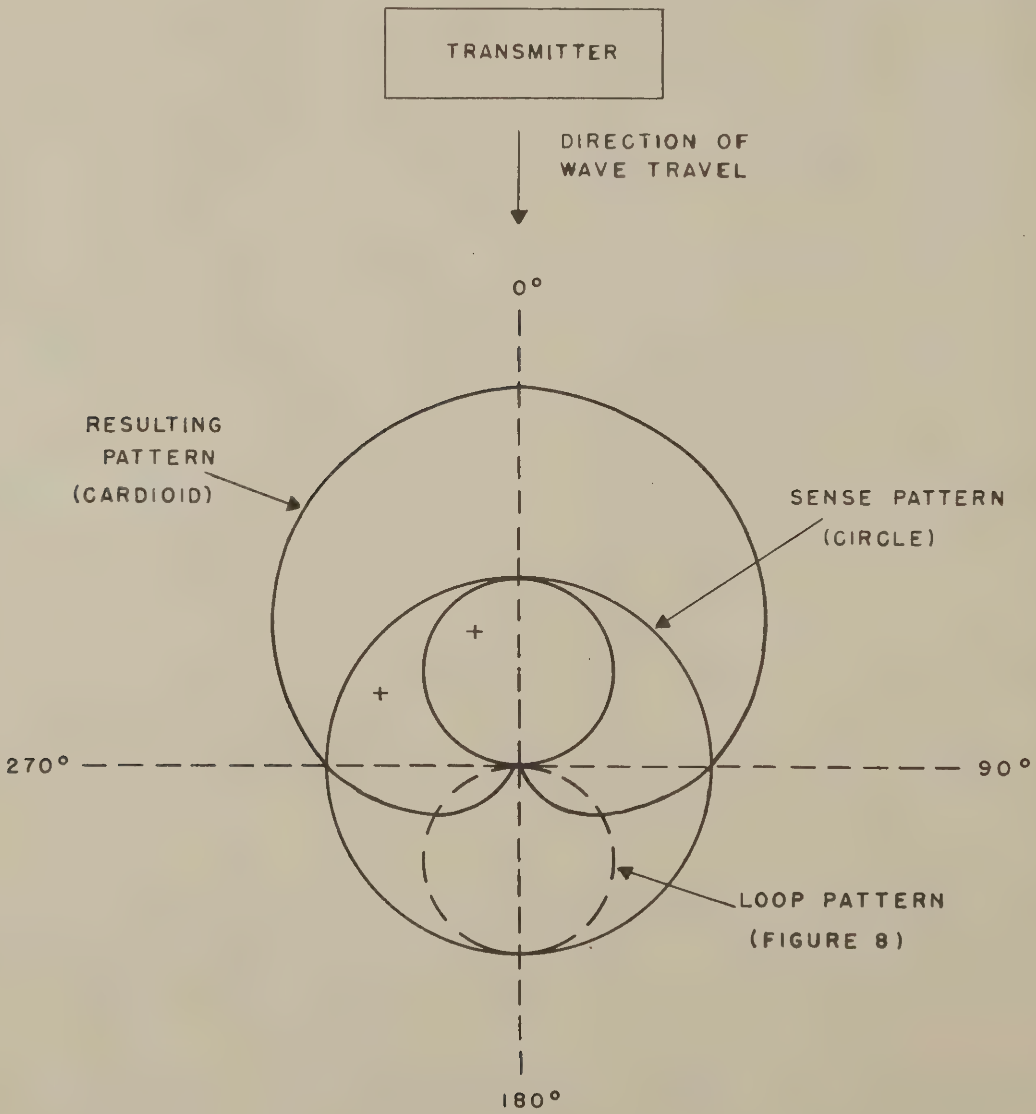


FIGURE 29. Cardioid Response Pattern.

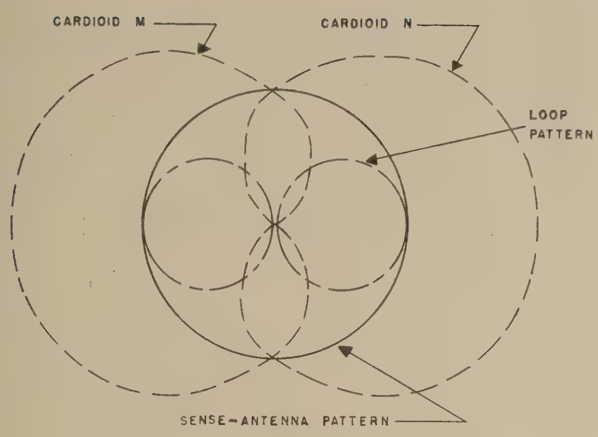


FIGURE 30. Switched Cardioid Patterns.

voltage output of V_3 and V_4. It measures only the difference between these two voltages.

Because the sense voltage is a common contributor to the voltages of V_3 and V_4, the difference between these two voltages is proportional to the loop voltage, which, in turn, depends on the position of the loop with respect to the direction of the received signal. When the loop voltage is zero (null position), the difference between the voltages of V_3 and V_4 is zero and the meter is at its center (on-bearing) position.

When the loop is rotated from the bearing position, the loop voltage increases and produces a proportional differential voltage across V_3 and V_4. Depending upon the position of the loop with respect to the bearing position, this differential voltage will cause the meter to deflect to the right or left. Electronic switching, then, is analogous to the mechanical switching described above as far as the response of the meter is concerned.

The voltages developed at various parts of the circuit of figure 32 are shown in figure 33. The resultant loop voltage appearing across the primary of the input transformer when the loop

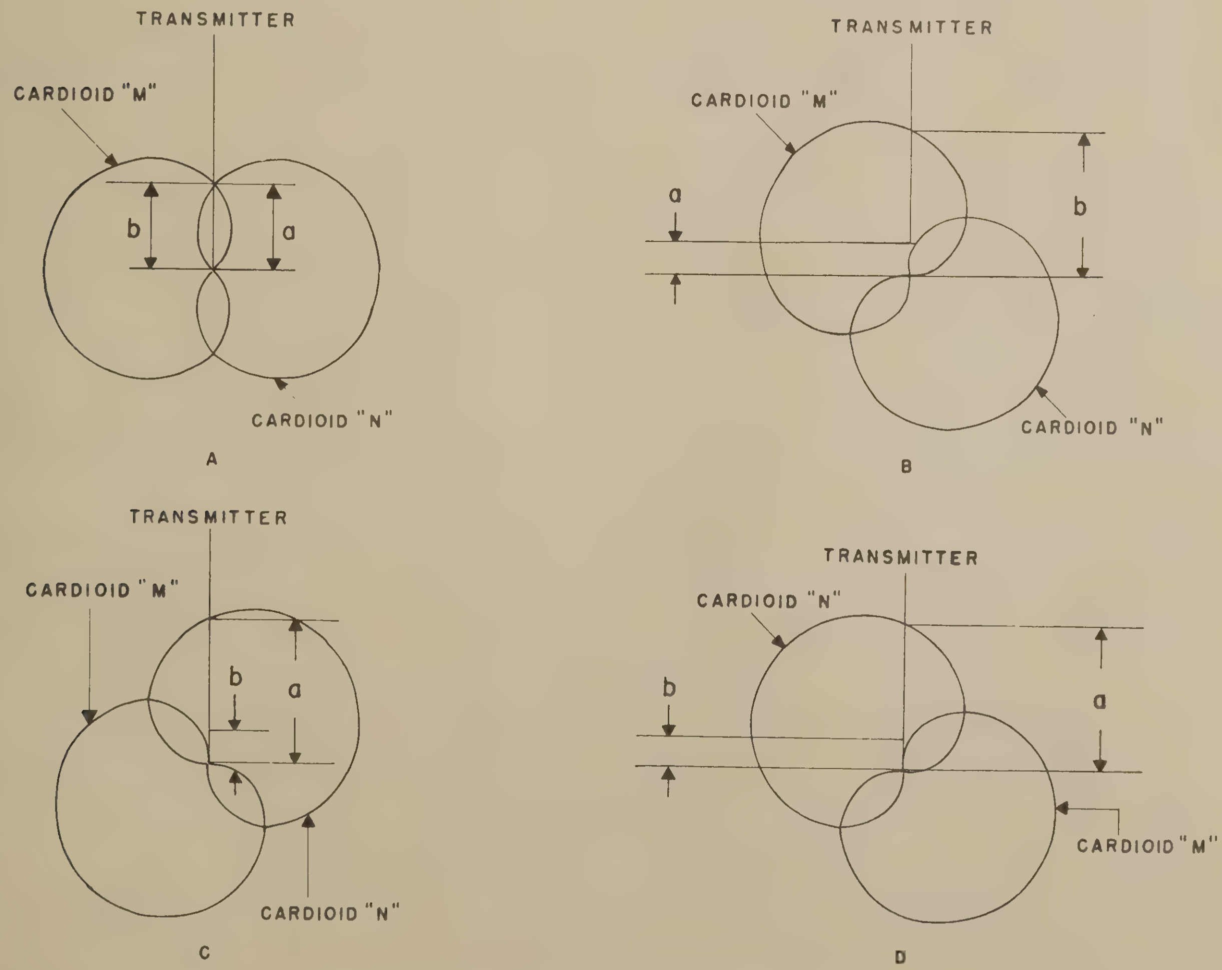


FIGURE 31. Cardioid Patterns at Different Loop Positions.

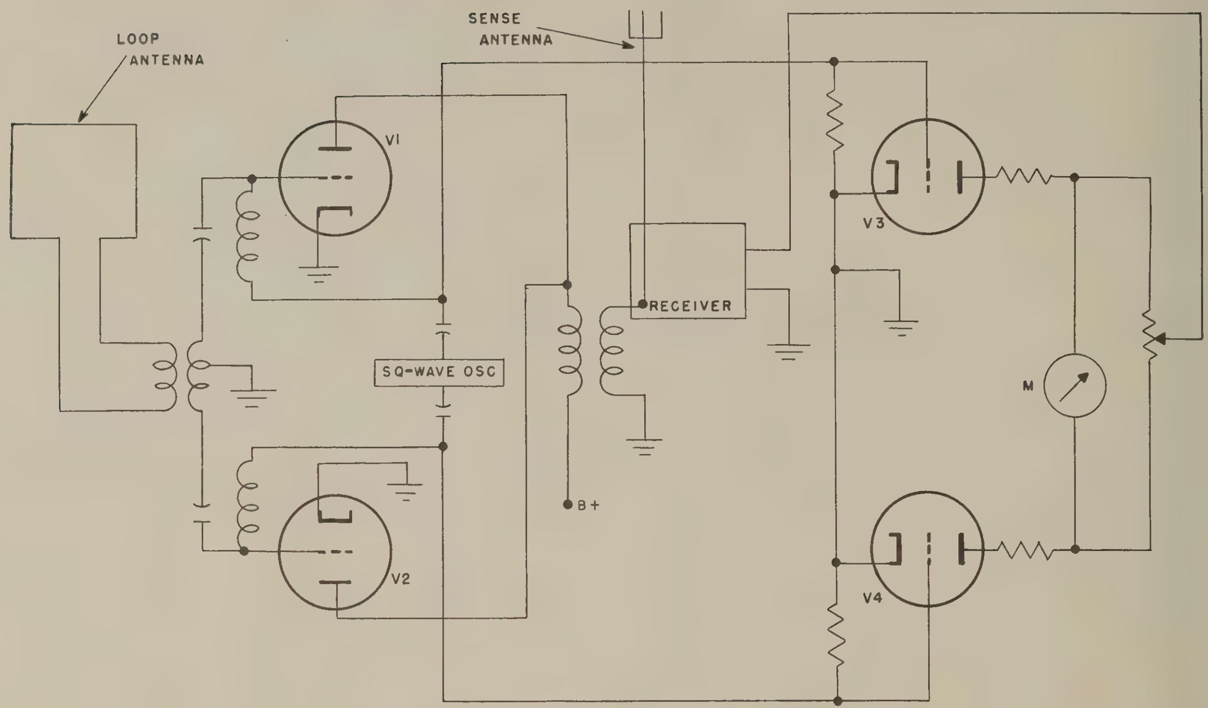


FIGURE 32. Basic Electronic Switching System.

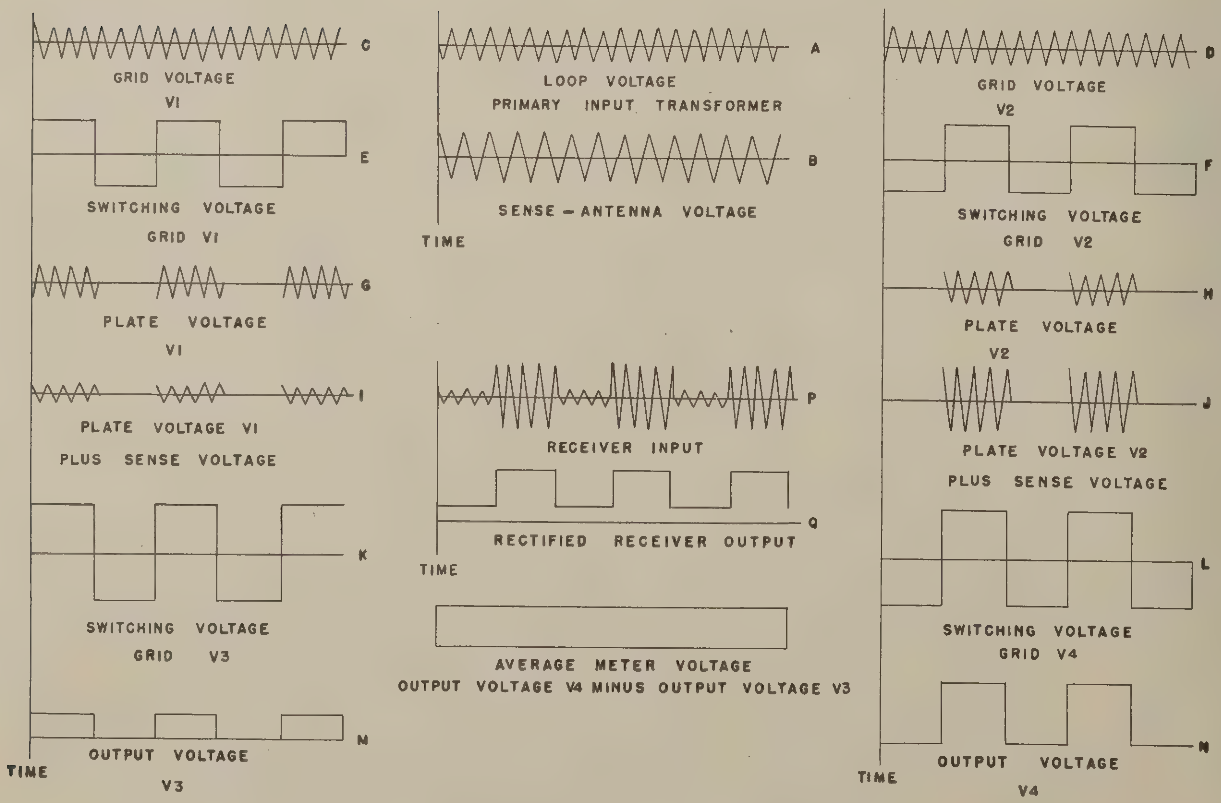


FIGURE 33. Voltage Relationship for Electronic Switching.

is rotated to the right of the null (bearing) position is 90° out of phase with the sense voltage in the resistance-loaded sense antenna as shown in curves A and B, but the loop voltage across either half of the secondary winding is 90° out of phase with the primary voltage because of the resonant transformer effect.

The secondary voltages, therefore, are either in phase or 180° out of phase with the sense voltage, which is the required relationship for proper sense indication. Also, the loop voltages and the audio switching voltages applied to the grids of input amplifiers V_1 and V_2 are 180° out of phase (curves *C, D, E,* and *F* of figure 33).

As tubes V_1 and V_2 are alternately switched off and on by the negative and positive half-cycles of the switching voltage, pulses of rf voltage are produced at their plates (curves G and H of figure 33). These pulses are equal in amplitude but 180° out of phase with each other and are alternately combined with the sense-antenna voltage at the receiver input (curves I and J of figure 33).

Because of the 180° phase relationship of the rf voltages in these pulses, the plate signal voltage of V_1 subtracts from the sense voltage, while the plate signal voltage of V_2 adds to this voltage. The alternate subtraction and addition of the loop and sense voltages produce the wave shape shown as the receiver input (curve P of figure 33), which is an rf wave modulated at the frequency of the switching voltage. The peaks and troughs of the wave are equal to the sum and difference of the sense and loop voltages, respectively. They are, therefore, proportional to the radius vectors of the two crossed-cardioid patterns shown in figure 30.

This modulated wave, after being amplified and detected (curve *Q* of figure 33), becomes a dc voltage pulsating in amplitude at the switching frequency rate. It is then applied in parallel to the plates of the synchronous rectifier tubes, V_3 and V_4. At any one instant, however, only one of these tubes is rectifying, because of the presence of the switching voltage (curves K and L of figure 33), which alternately drives one or the other of the tubes to cutoff. Therefore, one rectifier, V_3, will rectify the trough of the dc voltage wave (curve M of figure 33) and the other rectifier, V_4, will rectify the peak of the wave (curve *N* of figure 33).

Since these two rectified voltages are applied oppositely to the zero-center meter, the meter pointer tends to deflect in both directions. Actually, however, the meter pointer assumes a stationary deflection in a direction (right or left) determined by the predominating voltage, which in this case is to the right. The amount of deflection is proportional to the difference between the two rectified voltages, which, as previously explained, is proportional to the loop voltage and, therefore, to the degree of rotation of the loop from the null (or bearing) position.

As the loop approaches the null position, the loop voltage and consequently the amplitude variations at the receiver output approach zero. At exact null, the loop signal and its modulation disappear, leaving only the output of the sense antenna as an rf carrier. Thus, when the input wave is unmodulated, the rectified receiver output is zero and no deflecting voltage is applied to the meter, which then assumes a center-zero, or on-bearing, position.

When the loop is rotated beyond the null position but on the side opposite from that considered above, the loop voltage begins to increase, but it is reversed in phase from the voltage originally considered. This causes the plate signal voltages of tubes V_1 and V_2 also to reverse in phase by 180°. Thus, the output of V_1 adds to the sense voltage, while the output of V_2 subtracts from this voltage. This causes the troughs shown in curve P of figure 33 to become peaks.

The new wave, after detection and application to the synchronous rectifiers, causes the output of V_3 to be greater than that of V_4. Therefore, the meter deflects to the left a distance proportional to the voltage across V_3 minus the voltage across V_4. This again indicates an off-bearing position of the direction finder (or radio compass) but in the direction opposite from that considered originally.

Compass operation of the AN/ARN–7 is similar to the basic system described above. The voltage relationships are, for all practical purposes, about the same as shown in figure 33, except that the output from the synchronous rectifier (V_3 and V_4) is applied to a loop motor which rotates the loop toward the null. The direction of rotation depends (as previously explained) on the relative position of the loop with respect to the direction of arrival of the radiated signal to which the receiver is tuned. The special circuits involved and their operation will be studied in the following paragraphs.

Compass Position of Function Switch. On COMPASS position of *S*35, all tubes and circuits of the AN/ARN–7 are placed in operation. Both the antenna relay, RE–13, and the loop relay, RE–14, are de-energized, which is the position shown in the complete schematic diagram. We shall first study what each section of the function switch *S*35 does in the COMPASS position.

*S*35A (see radio control box C–4/ARN–1 on Chart C–258) completes the primary dc power circuit to the power-input relay coil (RE–8). The energized contacts of RE–8 supply dc and 400-cycle ac power to the set. Therefore, *S*35A does the same thing for each type of operation—it energizes RE–8.

*S*35B grounds the rf gain line (*L*17 in BK–22K) that leads to the cathodes of the first rf, second rf, and first detector (mixer) tubes. This permits the rf circuits to operate at maximum gain, controlled by avc action only. For antenna and loop operation, resistor *R*79B was inserted as a gain control as previously explained.

*S*35C connects the headset jack in series with the variable arm of resistor *R*79A (5,000Ω). Potentiometer *R*79A is connected across the audio output secondary through the audio line (B–1). Therefore, on COMPASS position the audio output is controlled by an audio volume control.

In tracing that part of the audio circuit from *J*3 to *R*79A, you will note that an impedance-limiting resistor, *R*82 (330Ω), is in series between the two points. Also, through *S*35F and *S*35G, resistor *R*79B is placed in parallel with *R*82. Insofar as control of the audio output is concerned, these two resistors serve no useful purpose. Briefly, they are put into the circuit to prevent the interphone input from being shorted to ground when *R*79A is moved near the ground end. This happens when the compass output is interconnected with other radio circuits through the pilot's control panel in a complete radio installation in an aircraft. (Aircraft systems installation will be studied in a later course.)

On COMPASS position, *S*35D and *S*35E are not used, since their fixed contacts have no connection. (Their purpose on ANTENNA and LOOP positions has been discussed.)

20. Special Circuits for Compass Operation

You have been shown that the resultant loop voltage will either lead or lag by 90° (depending upon which edge is nearest the source of radio signal) the voltage developed by a single vertical sense antenna. It was also shown that to produce the directional qualities desired, these two voltages must be brought in phase or 180° out of phase. This is done by a *loop phaser* circuit.

The electronic switching and synchronizing voltage is provided by a 48-cycle audio oscillator, *VT*–96. The modulation of the resultant loop and sense voltages by the synchronizing voltage is performed in the modulator circuit of tube *VT*–105. Finally, the direction of rotation of the loop by the loop-drive motor is controlled by a pair of loop-control tubes (thyratrons *VT*–109) and associated circuits. The balance of this chapter will therefore be given to the study of these specific circuits required for automatic compass operation.

Loop Amplifier and Phaser Circuit. The resultant signal from the loop antenna is coupled through transformer *T*40 (band 1) to the grid of the loop-amplifier tube, *VT*–86. In the plate circuit, the signal is shifted 90° by the phaser, which consists of the parallel tuned circuit, *L*22 and *C*21. It is resonant to 40 kc. Since the lowest frequency the receiver tunes is 100 kc, the phaser will act like a capacitor at that frequency; that is, the current through *C*21 will be much greater than that through *L*22 and, therefore, I_c will lead the signal voltage. The same phase of signal is coupled to each grid of the modulator tubes through capacitors *C*19–2 and *C*19–1 (250$\mu\mu$f).

Balanced Modulator Circuit. The balanced modulator stage consists of a dual-triode tube, VT–105, whose grids are connected in parallel to the loop rf signal and whose plates are connected in push-pull to the primary of the output transformer, *T*44 (antenna tuning unit 602). Both tubes are biased to cutoff by the fixed bias developed across the common cathode-bias resistor, *R*66 (75kΩ).

The upper triode dc grid circuit is completed directly to the cathode through the grid load resistor, *R*73–1 (470kΩ), and *R*66, while the lower triode grid circuit is completed through its load resistor, *R*73–1, to ground and to the cathode through grounded contacts *S*37D of RE–14. Actually, the purpose for the cathode ground through the relay is to short *R*80, which is not used during compass operation.

For loop operation, the upper triode section operates normally as an rf amplifier and the lower

section is blocked with a sufficiently large bias when the energized contacts, *S*37D, open the ground to the cathode.

The operation of the cathode voltage-divider circuit of the modulator may be explained as follows: The cathode is connected to the positive dc source through the 200-kΩ dropping resistor, *R*21. This places about 10 volts of dc from cathode to ground, that is, across *R*56–1 (3,000Ω) and *R*66 (75kΩ) in parallel. This is sufficient bias to cut off the tubes insofar as the rf signals from the loop are concerned, but this stage will conduct for the signal from the 48-cycle oscillator, *VT*–96, whose output is connected in push-pull to the modulator grid circuit.

When the loop relay is energized, the short is removed from *R*80. This puts the series combination of *R*66 and *R*80 in parallel with *R*56–1 and the dc voltage source. Owing to their resistance ratio, about 4 volts will now appear across *R*66 and the remaining 6 volts across *R*80. The upper triode will operate as a typical Class A rf amplifier with 4-volt bias, while the lower triode will be at cutoff, since it still has the full 10-volt bias in its grid circuit, which is the desired condition for loop operation.

Since the output of the 48-cycle audio oscillator is connected in push-pull to the modulator grids, one grid is positive while the other grid is negative. Assume that the upper grid is positive while the lower grid is negative. The positive grid will overcome the negative bias, and the tube will conduct until the 48-cycle signal drives the grid negative. Each side of the grid will conduct 48 times per second, so that there will be 96 pulses of plate current per second in the output transformer.

Each time the tube conducts, it permits a part of the rf signal to pass through. The loop rf signal and the sense-antenna signal are mixed in the grid circuit of the first rf amplifier to give the resultant signal that is coupled through the superheterodyne section of the receiver. The various voltage relationships in the input and output circuits of the modulator are shown in figure 34 and are very similar to those of figure 33.

Synchronizing 48-cycle Oscillator. The oscillator uses a twin triode, VT–96, whose plates are connected in push-pull to a tuned transformer (*T*38 located at the upper extreme right of the schematic in Chart C–258) which is resonant to 48 cycles. It operates simply like a resistance-coupled amplifier in which the voltage developed by the output of one tube (one triode section) is applied to the input of the other.

The circuit will oscillate because each triode section produces a phase shift of 180° (the transformer at resonance acts like a resistive load). The frequency of oscillation is determined by the *RC* time constants of *C*4–5 discharging through *R*14–8 and *R*67 and of *C*4–4 discharging through *R*14–7 and *R*67. Each triode section conducts alternately until cutoff bias is reached by the voltage across its respective grid-leak bias resistor, *R*14–7 or *R*14–8.

Resistors *R*15–1 (2,000Ω) and *R*15–2 are plate load resistors connected across each half of the primary of the audio transformer, *T*38, which is tuned by *C*65C. The pulses of plate current excite the tuned transformer primary, which develops the 48-cycle audio voltage that is coupled into the tuned-grid circuit of the cathode-follower stage, *VT*–66. (Refer to the simplified diagram in figure 35 for an over-all view of the special compass circuits.)

Cathode-follower Circuit. This circuit is used to furnish the positive 48-cycle synchronizing voltage to the plates of the loop-control tubes. Located in the cathode-to-ground circuit is the cathode-follower load resistor, *R*16–2 (50kΩ), through which current will flow at a 48-cycle rate and develop a positive voltage for the loop-control tubes.

Tube *VT*–66 will conduct during the positive alternation of the 48-cycle grid signal voltage. During the negative alternations, the tube will be blocked and no current flows through *R*16–2, so that during that instant the plate voltage to the loop-control tubes is zero.

Resistor *R*38–1 (500kΩ) is a grid current-limiting resistor. Capacitor *C*60–2 connected from the plate to ground is a 0.05-μf high-voltage rf bypass. The *B*+ voltage line for the cathode follower and the 48-cycle oscillator is connected to the tubes at the center tap of the *T*38 primary through contacts *S*37F of RE–14.

Compass Output and Loop AVC Circuits. There are usually three different frequencies coupled through the superheterodyne section of the receiver on compass operation: the regular rf carrier, the regular audio (voice or tone) that came with the carrier, and the 48-cycle audio synchronizing voltage. After detection and amplification in the first audio amplifier, the

audio signal is capacitively coupled through $C6$ ($0.05\mu f$) to the grid circuit of the compass output stage.

Only the 48-cycle synchronizing voltage is amplified, however, because all other audio frequencies higher than about 60 cycles are rejected by the R-C filter composed of capacitor $C87$ ($0.004\mu f$) and resistor $R38$–4 ($500k\Omega$). (It was explained in the section on antenna operation how the audio signal is also applied at the same time to the audio output stage.)

The pentode section of the compass output tube, VT–93, serves as an audio amplifier for the 48-cycle loop-control signal. The plate circuit is connected to interstage filter pack 167, which resonates at 48 cycles. It is important for proper operation of the loop-control tubes that all audio signals be eliminated except the desired 48-cycle voltage. The filter pack helps to do this.

The diode sections of the compass output tube function as a full-wave diode circuit and provide avc bias for the loop amplifier and loop-control tubes. On the positive alternation of the 48-cycle signal, current flows from the positive-going diode plate to ground through either resistor, $R12$–5 or $R12$–3, and then through resistor $R28$–2 through the combination of part of resistor $R49$ and $R57$.

The loop-amplifier bias is taken from a junction point just above $R28$–2. This bias is proportional to the audio voltage and regulates the gain of the loop amplifier to maintain the proper relationship between the loop and antenna components combined in transformer $T44$.

Resistor $R49$ is the automatic sensitivity (bias) control that is located in the front of the receiver unit. It can be adjusted to change the bias on the loop-control and loop-amplifier tubes. This in turn stops excessive hunting (vibrating) of the indicator needles.

21. Loop-control Circuit

The loop-control circuit operates like an automatically controlled loop left-right switch. Depending on which tube conducts, the loop will be rotated right or left to the null point.

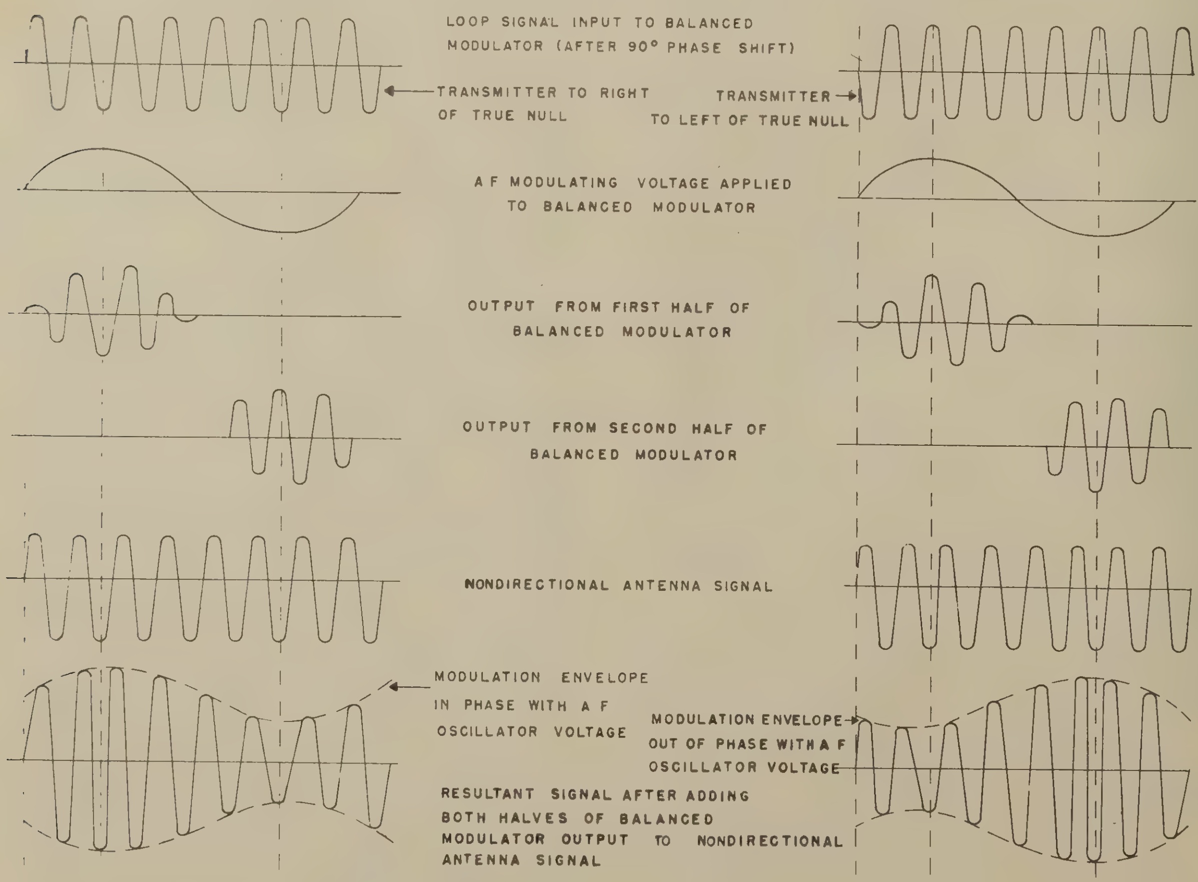


FIGURE 34. Balanced Modulator Input and Output.

The loop-control tubes, *VT*–109, are gaseous thyratrons. For such a tube to fire (draw plate current), its control grid and plate must be positive at the same instant. It can be seen that the grids are connected in push-pull to the center-tapped secondary of the filter pack transformer

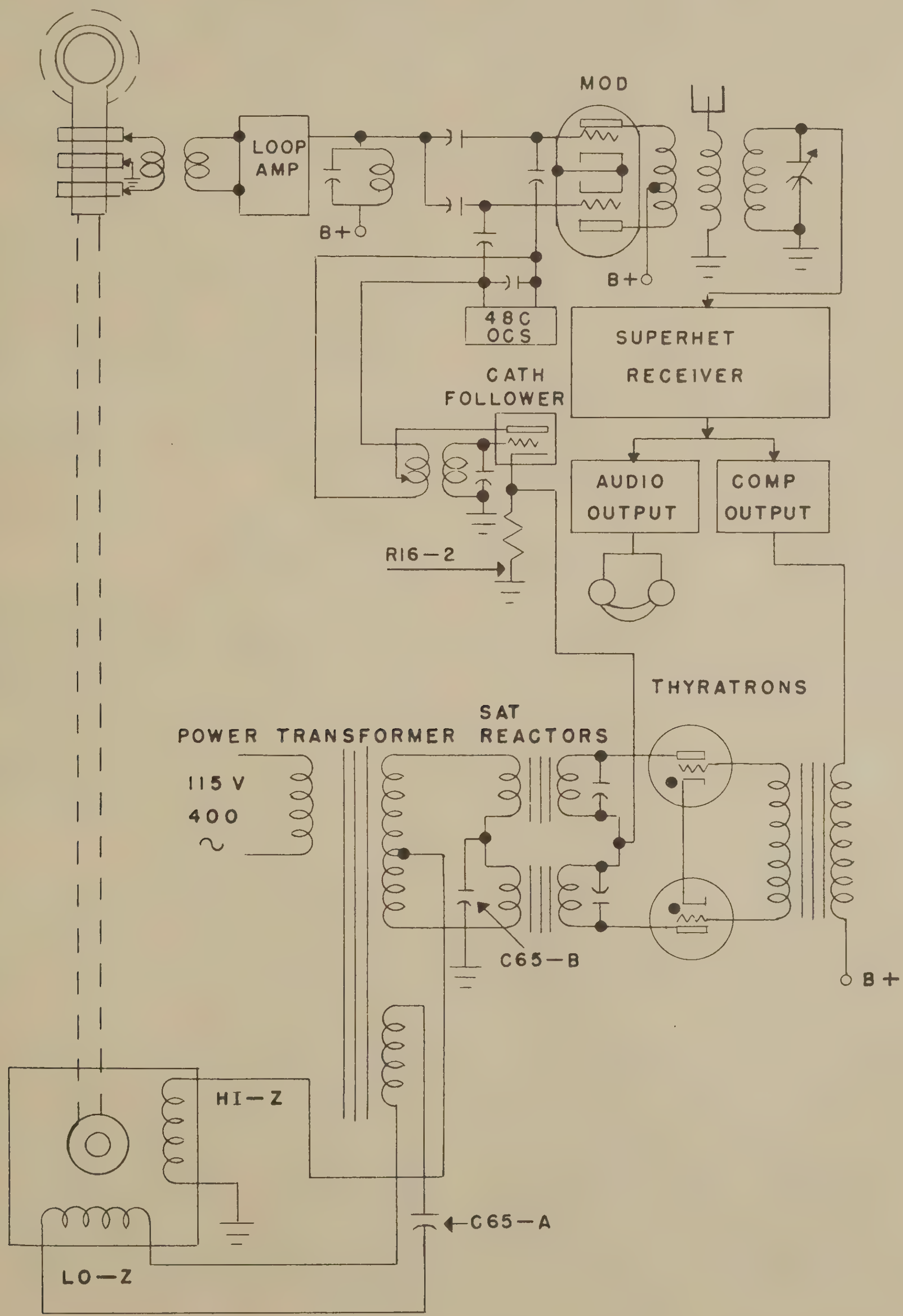


Figure 35. Special Compass Circuits Simplified.

(167), so that any instant one grid will be positive and the other negative. The plates, being connected in parallel to the source of the 48-cycle voltage (across *R*16–2), will both be either positive or zero at the same instant. Of course, the polarity of the grids and plates is changing 48 times per second.

The phase of the 48-cycle plate voltage is not affected by the resultant loop and sense voltages, but the phase of the same 48-cycle signal applied to the grids depends upon whether the sense and loop voltages were either in phase or 180° out of of phase. This in turn determines which of the loop-control tubes will have a positive grid at the same time its plate is positive and will therefore be caused to fire.

In the final analysis, the firing of one or the other loop-control tubes depends on which side of the loop antenna receives the transmitted signal first. (A careful study of each of the wave forms in figure 34 will help you to visualize the resultant signal that is applied to the grid circuit of the loop-control tubes.)

Assume that the receiver is tuned to a station that is to the right of true null and that, as a result, the 48-cycle pulses to the upper loop-control tube (upper *VT*–109 in Chart C–258–A) are synchronized (plate and grid positive at the same instant). The tube therefore sends strong 48-cycle current pulses into its connected saturable reactor until the loop is brought back to a null position.

In the meantime, the other loop-control tube (lower *VT*–109 in Chart C–258–A) cannot conduct, because when its grid is positive, the plate will be zero (no current pulse from the cathode follower and therefore no voltage across *R*16–2). This condition will exist until the loop has been reversed and the opposite side of the loop receives the signal first. When this happens, a 180° phase shift takes place in the modulator and first rf stage, and *VT*–109B (the lower tube) will conduct. This will cause the loop-drive motor to rotate the loop in a direction opposite to that caused by the conduction of *VT*–109A (the upper tube). This is a continuous effect, so that the loop's front will always point toward the transmitter producing the signal, regardless of the aircraft's heading.

The pointers of the indicators are also alined to point toward the transmitter; when the loop is at its null point, the true, relative, or reciprocal bearings can be read directly in degrees. (The operating principles of the Autosyn indicators were given in an earlier section.)

Resistors *R*38–2 and *R*38–3 (500Ω) in the loop-control grid circuits limit the grid current, while the plate series resistors, *R*52–1 and *R*52–2 (200Ω), limit the plate current surges, which are absorbed by capacitors *C*76–1A and *C*76–1B (0.5μf). Thus, the capacitors help to smooth out the 48-cycle pulses through the primary of the saturable reactors.

*R*58–1 is a 1,500-Ω cathode-bias resistor for the loop-control tubes. It is bypassed by a 50-μf electrolytic capacitor, *C*63B. The loop-control tubes (*VT*–109) draw an average current of 75 ma, but the peak plate current may reach a maximum value of 375 ma. Since they are gas tubes, the voltage drop across each tube is only about 14 volts. The tubes operate as triodes, since the screen grid is connected to the cathode and acts only as a shield.

22. Saturable Reactors

The saturable reactors (see fig. 36) are a matched pair of transformers of special design. The primary windings have a high dc resistance of 4,400 ohms, while the secondary windings have only 6 ohms. Each secondary winding (X_1, X_2) consists of two coils which are wound in opposition and connected in parallel. Therefore, no 400-cycle ac voltage will be induced in the primary, because the flux fields set up by the current in the two coils will cancel.

At their common connection, the secondaries are connected to ground through capacitor *C*65B (2μf) and contacts *S*37E of RE–14. Capacitor *C*65B blocks the dc damping current, which is supplied in parallel with the ac current to the high-*Z* winding of the loop-drive motor. It also neutralizes the residual reactance existing in the circuit when the reactor is saturated. The two ends of the secondaries are connected to the 400-cycle, 62-volt (from the center tap) secondary of power transformer 165 at terminals 6 and 8.

The center tap, terminal 7, is connected to the hot side of the high-*Z* loop-motor winding, the other side of which is grounded. (The circuit in Chart C–258–A is traced through terminals U–43 at PL–122.)

When the loop is at its null point, and therefore neither loop-control tube is firing, there is

practically no 400-cycle alternating current through the high-Z winding, because the reactors and the center-tapped 62-v winding form a balanced circuit. (Only the small dc damping current flows, as explained earlier, and prevents the motor from rotating before one of the thyratrons fires.)

The secondary windings of the reactors offer a high reactance ($X_L = 400\Omega$) to the 400-cycle current until one or the other of the loop-control tubes conducts. Then it decreases to a value approaching the dc resistance (6Ω) because the high value of pulsating current in the primary tends to saturate the iron core. In effect, this amounts to grounding the side of the 62-volt ac source to which the saturated reactor is connected. This unbalances the high-Z circuit, and current will flow through the high-Z winding.

Since the current through the low-Z winding is phased 90° (owing to $C65A$), the current through the high-Z winding will either lead or lag the current through the low-Z winding (depending on the direction of current flow) and the motor will rotate the loop to its null point.

The high-Z motor circuit is easily traced in the simplified diagram of figure 36. Assume that VT–109A conducts; then the impedance of the secondary winding (X_1) decreases, the loop-motor circuit will no longer be balanced, and there will be a current flow in the high-Z winding. With the instantaneous polarity across the 62-volt winding as shown in figure 36, the current flows down through L_1, out of the center tap (terminal 7), through the high-Z winding to ground, then up through $C65$–B and reactor X_1, and back to L_1, completing the circuit.

If the other control tube had fired instead (same instantaneous polarity), then the current flow would be down through the high-Z winding and back to L_2 through the center tap. Thus, it is obvious that the current through the high-Z winding when VT–109A was conducting will now lag the current of the low-Z winding by 90°, causing the motor to reverse its direction of rotation.

23. Maintenance and Troubleshooting

The radio compass receiver is a well-designed set and is properly adjusted to design specifications at the factory. The troubles that you as a radio mechanic will experience with this set are generally those that result from normal wear after a period of use, such as bad tubes, noisy filters, dirty relay and switch contacts, and, more often, worn or dirty contacts in the interconnecting plugs, broken or loose wiring, and open fuses.

It is obvious that the better you understand

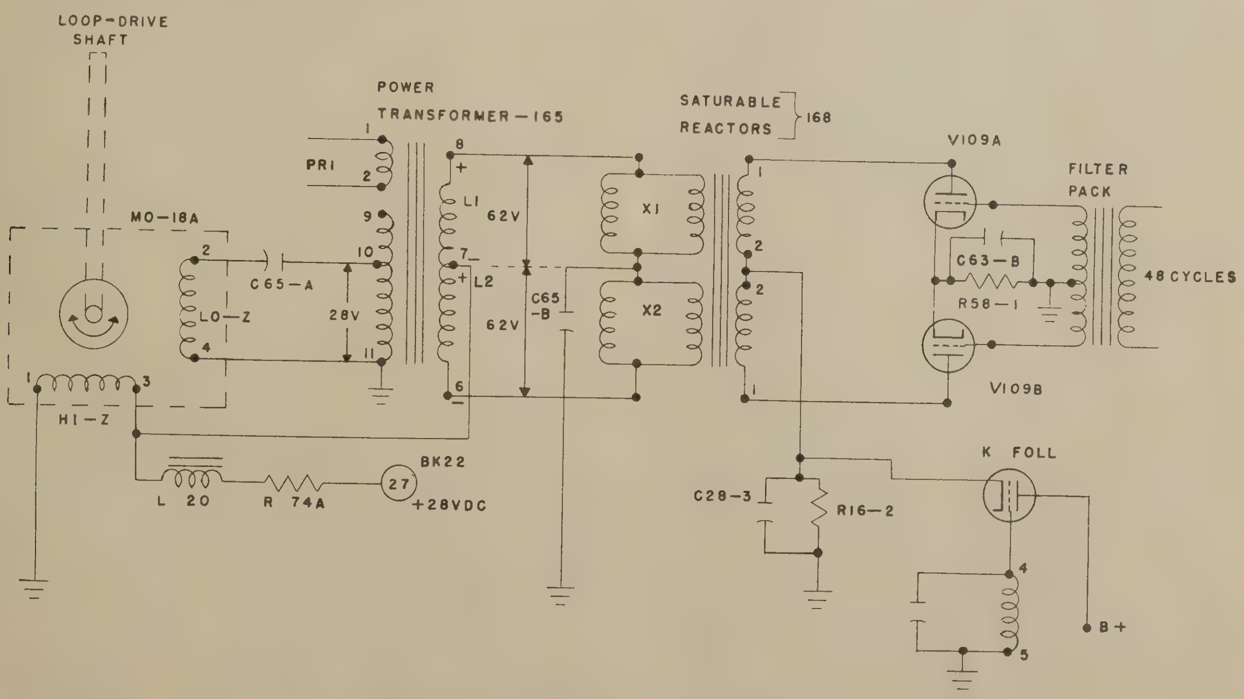


Figure 36. Saturable Reactors and Loop-motor Drive.

the operation of the various circuits in the schematic, the more easily you will be able to analyze a particular symptom and find the cause of the trouble. (As in previous studies in troubleshooting radio equipment, you are limited to "practicing" with the schematic rather than with the actual equipment; however, such practice serves as a basic and necessary preparation for the real thing.)

Common Problems. Proper use of the tuning meter can make troubleshooting the radio compass easier than finding trouble in a common receiver. You have already learned that the tuning meter is located in the second detector stage and how it reacts when tuning. (Trace the tuning meter circuit from either C–4/ARN–1 to the second detector tube.) By carefully observing abnormal reactions in the meter, you should be able to isolate a trouble to a stage or group of stages.

If the meter functions normally, but there is no output, the trouble must be somewhere in the audio output stage which follows it or in the headsets, cordage, or noise-silencing relay, RE–6. If the meter does not deflect to the left when the set is switched on, trouble is indicated either in the power supply or in the second detector. If, however, the meter shows a normal deflection to the left when the set is turned on but will give no deflection to the right when you attempt to tune in a radio station, then it can be reasonably assumed that the rf or i-f stages are defective.

Use these symptoms to isolate troubles. First make the usual visual and operating checks. If you note faulty operation, analyze what you have observed. Work in logical order and look for the most common trouble first.

A practical approach to troubleshooting the radio compass is to observe carefully the operation of the set on each position of the function switch and check the circuits where abnormal operation is observed. That is, first make sure that the ANTENNA position is operating normally. This eliminates eight tubes and the power supply as possible troubles. Next, check loop operation. Operate the loop left-right switch and watch the Autosyn indicators for proper operation. If LOOP position checks OK, this eliminates an additional two stages—the loop amplifier and modulator.

Lastly, switch to compass operation; abnormal operation of the indicators will isolate the trouble to the five stages used for automatic compass operation. (A comprehensive treatment of maintenance and troubleshooting problems for the radio compass is beyond the requirements of this course. This information may be found in Section V of the *Handbook of Maintenance Instructions,* TO AN16–30ARN7–3.)

Installation Adjustments. There are two required adjustments in the installation of any radio compass receiver: the autosensitivity and the synchronization of the control boxes to the ganged capacitors of the receiver.

Autosensitivity. As previously explained, *R*49 controls the sensitivity of the loop-control circuits in automatic compass operations to small changes in loop signal strength and adjusts the hunting of the loop to the desired value. The adjustment is made by tuning the receiver to a station about 50 miles away and adjusting the control to a sensitivity such that when the loop is rotated one degree from its bearing position, the automatic control circuits will restore it to within one half of a degree of the original position.

Synchronization of control boxes. The tuning crank and calibrated dial assembly of both control boxes must be synchronized with the ganged tuning capacitor of the receiver so that the control boxes will indicate the true frequency to which the receiver is tuned. This is done by turning the tuning crank backward (counterclockwise) to the end which fully meshes the tuning capacitor. Disconnect the cables from the control boxes. Switch to the high band and rotate each tuning crank until the ALIGN mark at the low end of the dial is exactly under the hairline of the frequency indicator. Reconnect both cables. The boxes should now be synchronized.

Summary

The radio compass receiver has been presented in its three modes or types of operation. On ANTENNA position of the function switch, the set operates simply as a sensitive superheterodyne receiver capable of receiving voice, tone, or cw signals, like any other communications receiver, through its sense antenna.

On LOOP position of the function switch, the directive loop antenna is substituted for the sense antenna so that the set can be used as a homing

device as well as for communications. The shielded loop assembly also helps to reduce static pickup during bad-weather reception.

On COMPASS position, the special automatic loop-control circuits are placed in operation and the set operates as an automatic direction finder, which is its primary purpose in an aircraft. The indicators continually indicate to the pilot and navigator the relative bearing of the aircraft with respect to the particular station to which the receiver is tuned. In this position, the navigator can quickly tune to two or three stations and obtain bearings which can be plotted to obtain a fix (position). Also, in COMPASS position, the set still functions as a communications receiver, so that weather reports or any other voice or code transmissions can be heard from the station tuned in.

REVIEW QUESTIONS

The following questions are study aids. Your answers are not to be submitted to the USAF Extension Course Institute for grading. Correct answers will be found at the end of this text.

1. What are the primary power requirements of radio compass unit R–5/ARN–7?
2. When will the ALIGN mark appear on the tuning dial?
3. How many separate lines connect the remote-control box to the junction-box relay? Name the circuits associated with the following lines: T–58, G–40, L–4, B–1, S–28.
4. How are the primary power circuits protected?
5. How are the lines from the fixed terminals of the junction box connected to the receiver unit?
6. What components are included in loop assembly LP–21–LM?
7. What compounds are used in the dehydrator unit? What indication is given when the dehydrator is saturated?
8. Explain the operation of the automatic indicator system (I–81A or I–82A).
9. Where is the 115-volt, 400-cycle ac applied in the receiver?
10. When is the loop relay energized?
11. How is the sense-antenna signal coupled to the first rf stage on band 4?
12. On band 2, what components form the i-f wave trap in the first rf stage? What is its resonant frequency?
13. How is the receiver volume controlled on ANTENNA position of the function switch?
14. How is the gain of the i-f amplifier reduced on loop operation? Why?
15. Give the reference symbols and values of the following components in the second detector stage: (*a*) diode avc load, (*b*) diode second detector load, (*c*) diode second detector filter capacitor, (*d*) delayed avc biasing resistor, and (*e*) audio feedback decoupling resistor.
16. Why does the average current through the tuning meter decrease as the receiver is tuned to a station?
17. Why is a spark suppressor necessary at the ratchet-motor assembly in the band-change motor unit? List the reference symbols of the components forming the spark suppressor.
18. Explain the theory of operation of the loop-drive motor for manual control.
19. What provision is made for receiving cw code transmission in the compass receiver?
20. What does the cardioid response pattern show?
21. What type of voltage is fed to the synchronous rectifier of figure 32?
22. In figure 32, what voltage does meter *M* measure? Upon what does the strength of this voltage depend?
23. What is the required phase relationship between the loop and sense antenna voltages when they are combined at the receiver input (see fig. 32) for proper sense direction?

24. Why doesn't the meter M (see fig. 32) deflect when the loop is at null position?

25. What change in loop position is required to cause the meter M (see fig. 32) to change from a right to a left deflection? How will this affect the phase of the loop voltage?

26. Explain how the required power is supplied to the compass receiver for compass operation.

27. What is the purpose of the loop-phaser circuit?

28. How are the grids and plates of the modulator tubes electrically connected with respect to the loop signal?

29. Why is it necessary to ground the modulator cathode through RE–14?

30. How are the 48-cycle oscillator and cathode-follower circuits disabled during antenna and loop operation?

31. How are signals higher than 60 cycles rejected at the grid circuit of the compass output stage?

32. Explain the operation and purpose of the diode section of the compass output tube.

33. In automatic compass operation, what additional stages are required other than those stages used for antenna operation?

34. Briefly state the purpose of each stage listed in question 33.

RADIO COMPASS AN/ARN–6

IN THIS CHAPTER, you will study another radio compass, the AN/ARN–6, which is designed to serve the same purpose in the same manner as the AN/ARN–7. We shall avoid repetition of pertinent detailed material applicable to the AN/ARN–6 which was presented in chapter 2, but a functional analysis of the circuit features of this set will be studied with the aid of the complete AN/ARN–6 schematic.

In comparison with the AN/ARN–7, the AN/ARN–6 is a smaller and lighter set which was designed primarily for use in fighter aircraft, where space is limited. The only power source required is the 24–28-volt aircraft central power system. All ac voltage is furnished by a vibrator operating at 100 cycles. No high-voltage rectifier is required, since the 24–28-volt primary dc voltage is applied directly to the plates of the amplifier tubes. Thus, the need for a heavy multiwinding power transformer is eliminated.

The junction box and its relay have been incorporated in the mounting, making it necessary to use a special adapter (extension cable) if voltage measurements are to be taken. A beat-frequency oscillator is used for cw reception during antenna and loop operation, and a tone oscillator is used for compass operation. Current through the tuning meter is controlled by a rectifier and an amplifier tube. An i-f trap is placed in the antenna circuit, which is effective on bands 2, 3, and 4.

The loop on the ARN–6 is smaller than the one used with the ARN–7. The loop housing and indicators are filled with dry nitrogen gas and sealed. The ARN–6 is remotely controlled in the same manner as the ARN–7. The control boxes are different in construction, but the same controls are used. The flexible cables are identical. The length of shielded cable from the loop to the receiver of the ARN–6 is not critical.

24. General Description

A complete dual-control AN/ARN–6 radio compass installation is shown in figure 37. The installation includes the following items: receiver unit R–101A and its mounting, MT–273A; two control boxes, C–149A, and mounting MT–275; pilot's indicator ID–90A; navigator's indicator ID–92A; loop unit AS–313–A; sense antenna and coupling CU–65; flexible tuning shaft MC–124 and coupling MC–203–A; and the required interconnecting cording and cabling as shown in the diagram. Two headsets (HS–33) are also required. The entire installation weighs about 75 pounds. The receiver unit alone weighs 35 pounds and the antenna unit 14 pounds.

(*Note:* The letter "A" following the unit number, for example, *R*101A, means that minor changes were made in receiver unit *R*101 as originally designed. The associated units may also carry the suffix "A," for example, ID–90A.)

Operating Characteristics. Fourteen of the 16 tubes used in the AN/ARN–6 are typical receiving tubes, while the two loop-control tubes are gaseous thyratrons. When either one of the thyratrons is conducting as the loop is rotating toward null, the dc plate current flow will measure 19 ma. The dc and ac voltages measured from the plate socket terminal to ground will be 30 volts and 120 volts, respectively. The heaters require 600 ma at 6.3 volts.

The frequency range from 100 to 1,750 kilocycles is covered in four bands as follows: band 1—100 to 200 kc, band 2—200 to 410 kc, band 3—410 to 850 kc, and band 4—850 to 1,750 kc. A 455-kc i-f is used on band 1, and an i-f of 142.5 kc is used on bands 2, 3, and 4.

There are two types of cw reception. During cw reception on *antenna* or *loop* operation, a BFO is used which operates at 455.9 kc for band 1 and at 143.4 kc for the remaining three bands. For *compass* operation, a 900-cycle tone oscillator is used to modulate the cw signal as it passes through the i-f channels.

The sense-antenna input circuit is designed to operate from a low-capacitance transmission line properly matched to a standard 40-to-100-micromicrofarad antenna.

The loop antenna is a low-impedance iron-core loop of 9 turns electrically center-tapped by a shunt coil of 12 turns and electrostatically shielded. The cord connecting the loop to the receiver is shielded and has a distributed capacitance of about 150 micromicrofarads between terminals B and C.

The audio output impedance at the phone

jack is 300 ohms, which is designed for use with headsets HS–33 or HS–38.

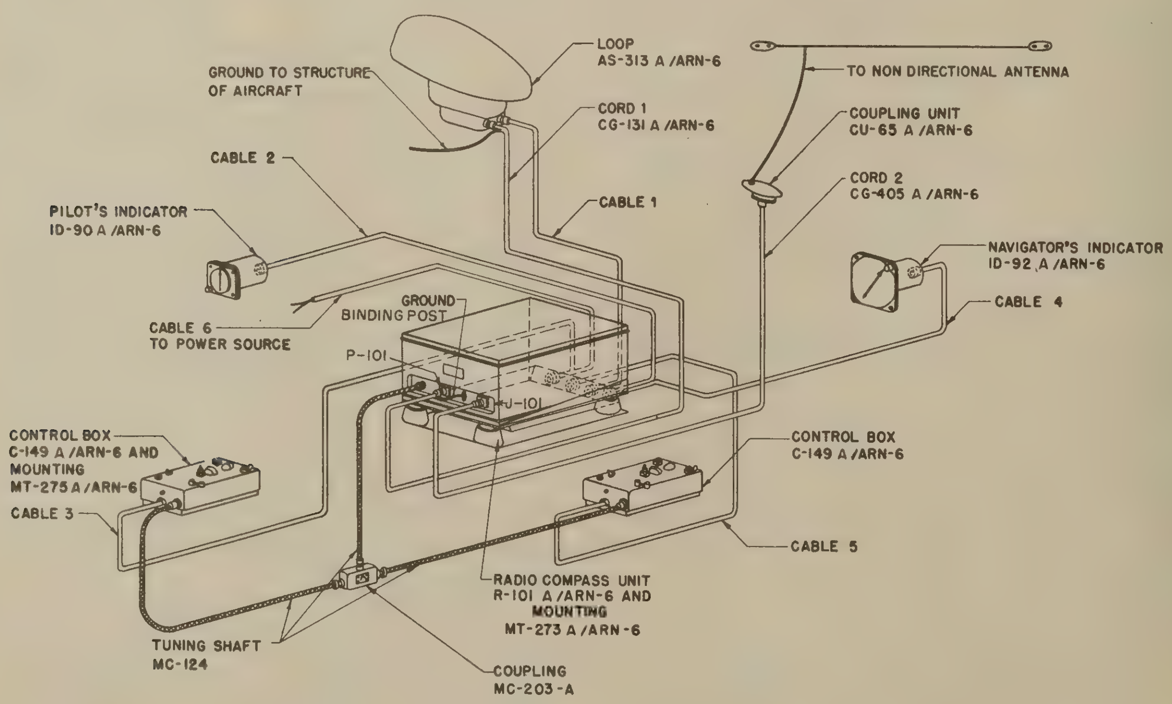
At a test frequency of 850 kc, modulated 30 percent, applied to the grid of the first rf amplifier, the sensitivity is 8 microvolts or better for the standard output of 50 milliwatts. A 50-micromicrofarad capacitor as dummy antenna is required. The volume control is set at maximum sensitivity (fully clockwise), and the sensitivity control is set for a standard 4:1 signal-to-noise ratio. (This means that for a 50-milliwatt output, not more than 12.5 milliwatts may be noise voltage. The noise is measured with the test signal removed.)

The sensitivity of the set is best at the high end of band 4 for both the sense and loop antennas. On ANT the input may be as low as 3 microvolts for standard output, as compared with 20 to 35 microvolts per meter for loop operation. In a sensitive, well-alined set, the modulated 8-mv test signal at the first rf grid will be amplified to 0.3 volt at the grid of the audio driver—a gain of 37,500!

The compass accuracy is normally within $\pm 1°$ of true bearing at all frequencies and field strengths from 25 microvolts per meter, up. The hunting can be limited by proper adjustment of the hunt control, *R*1105, from 0° to $\pm 1°$. The speed of taking bearings is from 4 to 7 seconds for 170° of rotation.

The average power required to operate this set is 4 amperes at 26.5 volts dc (106 watts).

Radio Compass Unit. The receiver, *R*–101/ARN–6, is contained in an aluminum housing with removable top and bottom covers. The overall dimensions are $15\frac{1}{4} \times 11\frac{3}{8} \times 7\frac{5}{8}$ inches. A recess in the front panel contains a three-prong male contact connector, *J*101, for the sense antenna input, a ground binding post, the tuning-shaft fitting, and a carrying handle (see fig. 38A). A recess in the rear panel contains a 22-contact male connector (banana plugs), *P*102, which fits into a female connector strip, *J*501, in the mounting. A guide pin (*O*107) is provided at each end of *P*102. (See fig. 38.)



CORDING AND INTERCONNECTION DIAGRAM (DUAL CONTROL)

FIGURE 37. Cording and Interconnection Diagram.

Included within the radio compass unit are the circuit elements which make up the compass circuit. These consist of a superheterodyne receiver circuit, the automatic loop-control circuit,

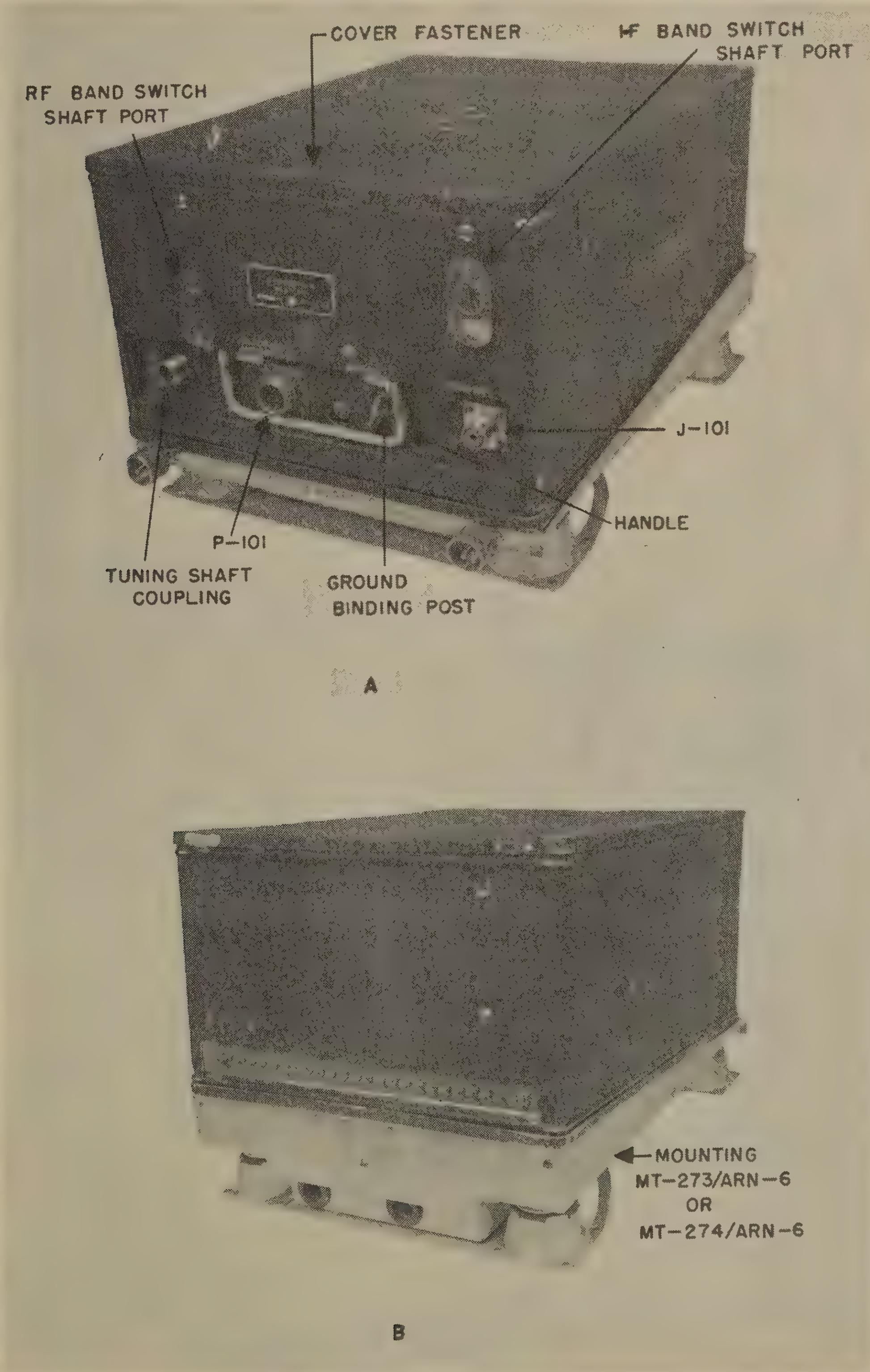


Figure 38. Radio Compass Unit R–101A/ARN–6.
A. Front View.
B. Rear View.

the vibrator power-supply circuit, and necessary circuits to provide for accurate tuning and dual identification of unmodulated radio stations.

Mounting. The mounting, MT–273A/ARN–6 (see fig. 39), is an aluminum frame with a built-in junction board and control-switch relay in the base. The mounting sits on four rubber shock absorbers. The female connector strip, *J*501, located in the back of the mounting, makes electrical connection with the similar connector strip, *P*102, on the back of the radio compass unit as it is slid into the mounting. Two locking knobs on the front of the mounting hold the radio compass unit in place. The junction board provides for electrical interconnection of various components. The relay transfers control from one control box to the other.

Control Box. The control boxes, C–149A/ARN–6 (see fig. 40), contain the necessary circuit elements and controls to provide complete remote control of the radio compass. The front panel contains the function (or selector) switch, *S*305, tuning meter *M*301, loop L-R switch *S*304, light control *X*301 (*H*307, dial light, and *H*309, spare dial light), band switch *S*303, control switch *S*301, cw-voice switch *S*306, tuning crank *O*302, and audio volume control *R*302. Located on the lower end are the phone jack, *J*301, and the flexible tuning shaft fitting. All electrical connections are made by a male connector, *P*301 (25 contacts and two guide pins), located on the bottom of the control box. *P*301 fits into a similar female connector, *J*302, located on the control-box mounting.

Loop. In figure 41, detail A shows the complete loop assembly, AS–313A/ARN–6, in its housing. Detail B exposes the loop with its copper-mesh shield within the sealed glass dome. The loop may be mounted as shown in detail B (housing plate removed) inside the pilot's cockpit

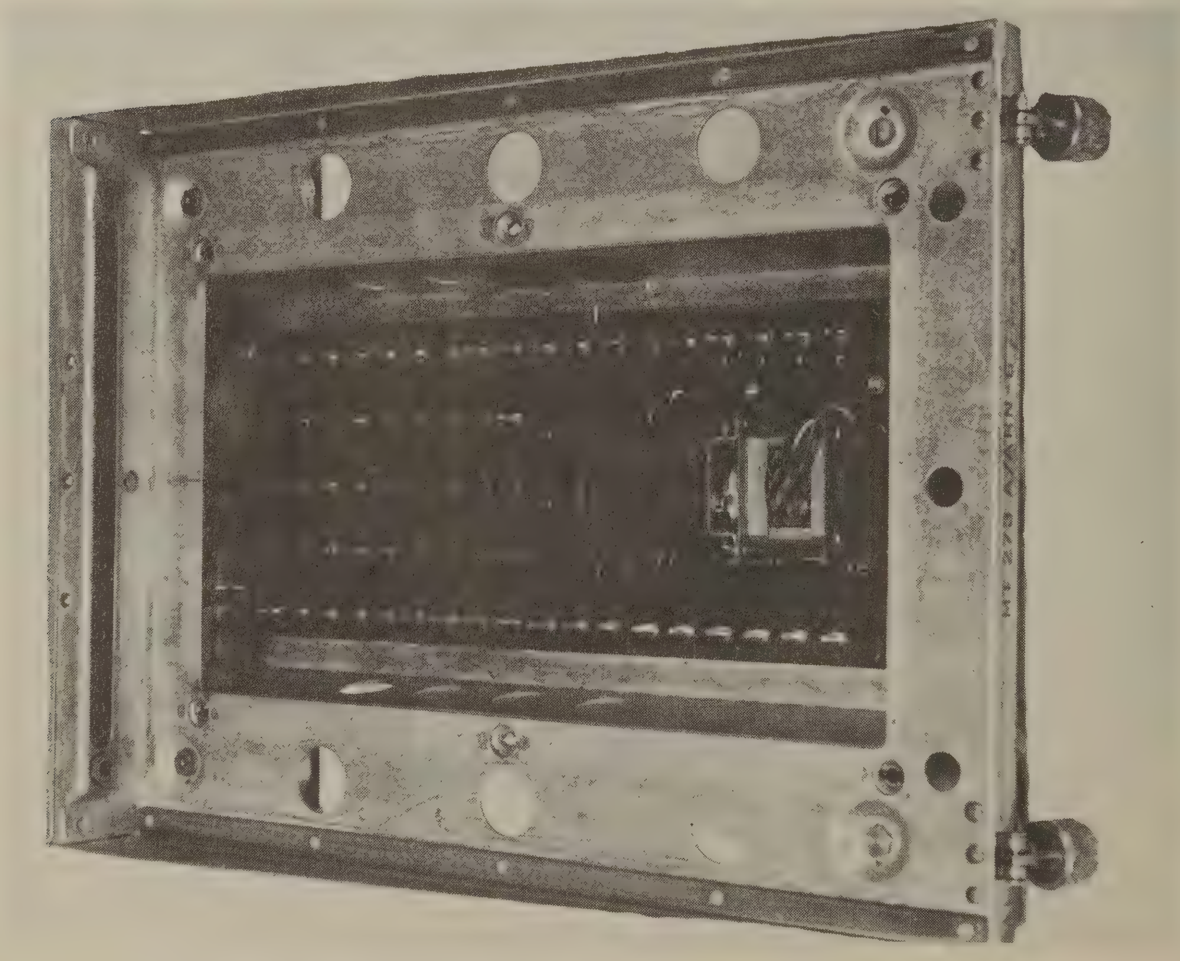


FIGURE 39. Mounting MT–273A/ARN–6, Cover Plate Removed.

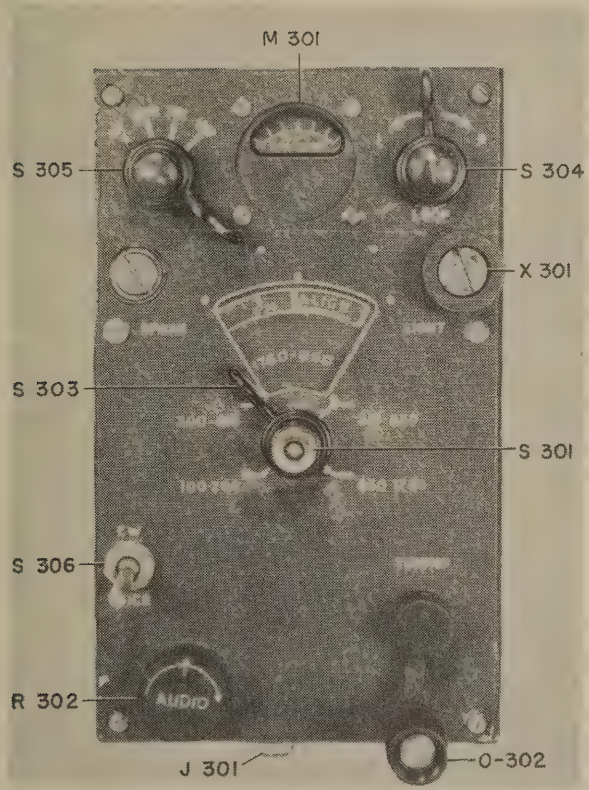


FIGURE 40. Control Box C-149A/ARN-6.

in fighter aircraft. Detail C shows the bottom of the loop with the adjustment cover plate and the two male receptacles, *P*701 and *P*702.

In detail D, the adjustment cover plate is removed, revealing the compensator dial and adjustment screws. The proper adjustment of the screws corrects for compass deviation errors. The loop-drive motor, Autosyn transmitter, and remote indicator system are very similar to those used in the AN/ARN-7 radio compass. The entire loop is hermetically sealed and cannot be opened without special tools.

Indicators. The indicators (see fig. 42) are very similar to those used in the AN/ARN-7. The scale of the navigator's indicator (ID-92A/ARN-6) is identical, but the pilot's indicator (ID-90A/ARN-6) scale is graduated every two degrees and can be manually rotated, whereas in the ARN-7 it was graduated every five degrees and fixed. The same type of Autosyn motor operates the indicators, except that the power frequency is 100 cycles ac instead of the 400-cycle power used in the AN/ARN-7.

Coupling Unit. The coupling unit, CU-65/ARN-6 (see fig. 43), is a small streamlined inclosure mounted through a raintight plate to the skin of the aircraft. The coupling provides a female connector for the sense-antenna transmission line and an antenna input terminal, *J*601. Through the transmission line it electrically connects the antenna to the receiver.

25. Block Diagram Description

You will begin your study with a general description of the over-all functioning of AN/ARN-6 equipment with the aid of the block diagram of figure 44. This description will serve as a review of the radio compass principles covered in chapter 2 and will also acquaint you with the make-up of the AN/ARN-6 equipment as a whole. It is suggested that you locate the stages shown in figure 44 in the complete schematic of the AN/ARN-6, Chart C-0-5-(d).

The block diagram of figure 44 shows all the electronic tubes and stages that are included in the complete radio compass receiver. It can be seen that the same familiar stages—the loop amplifier and modulator—are found between the loop and sense antennas as in the ARN-7, although the tubes are different. The arrows show the progression of the signal from the antennas through the various stages.

After detection, the audio component of the signal is applied to the audio output circuits and the 100-cycle synchronizing voltage is applied to the automatic compass control circuits in a manner similar to that of the ARN-7 radio compass. The superheterodyne receiver section of this set has more stages of rf, i-f, and audio amplification than are found in the ARN-7, but this is necessary to obtain sufficient over-all sensitivity, since the plates of all amplifier tubes are supplied with a low dc voltage (24-28 volts) directly from the primary power source.

The tuning meter is operated by circuits which are independent of the second detector. A portion of the i-f voltage is rectified and amplified as the source voltage for the meter. The vibrator stage (*V*102) supplies the 100-cycle synchronizing voltage to the modulator and loop-control tubes as well as supplying 100-cycle power to the Autosyn indicator system and the loop-drive motor.

As in the ARN-7, the low-*Z* winding is constantly connected to the vibrator power source (indicated by the closed arrow on the right side

of the loop-motor block diagram), while the application of the vibrator power to the high-impedance winding depends on the firing of the loop-control tubes in compass operation or the closing of the loop left-right switch in loop operation. The closed arrow symbols leading from the vibrator shows exactly where the vibrator power (source of all ac) is applied. The double-arrow symbol simply shows that the two indicators are controlled by the Autosyn transmitter, which is mechanically connected to the loop through the compensator and loop motor.

Figure 44 also shows plainly that the loop L-R switch and the loop-control stages perform the same function; that is, each applies the 100-cycle vibrator power to the high-impedance winding of the loop-drive motor, causing it to rotate. The L-R switch is, of course, controlled by the operator.

The loop-control tubes are automatically controlled by the signal phase applied to their grid circuits, which in turn depends upon the position of the loop with respect to the direction of arrival of the radio wave. That is, the direction in which the motor drives the loop depends (through the receiver circuits) on whether the loop signal leads or lags the sense signal; by this means, the loop is rotated so that the same side of the loop is always toward the transmitting station.

It can be seen then, that the over-all operation of the ARN–6 is the same as the ARN–7. Figures 45 and 46 have been included to show the resemblance between the parts layout of the ARN–6 and those of the ARN–7, as shown on corresponding illustrations (see figs. 18 and 19) in chapter 2.

In this chapter, the circuits of the AN/ARN–6 will be studied from the over-all schematic diagram, Chart C–0–5–(d), parts 1 and 2. The three

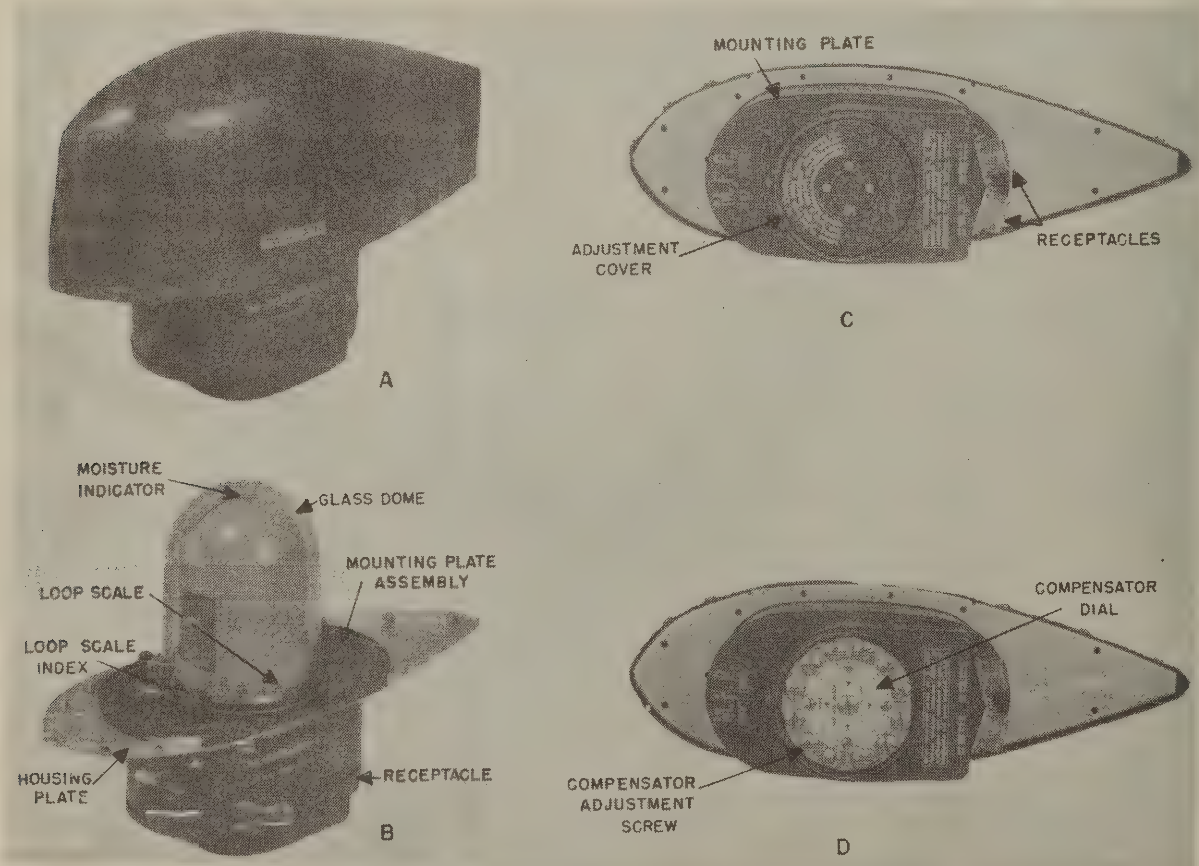


FIGURE 41. Loop AS–313A/ARN–6.
A. Complete Loop with Housing in Place.
B. Complete Loop with Housing Removed.
C. Bottom of Loop with Adjustment Cover in Place.
D. Bottom of Loop with Adjustment Cover Removed.

types of operation will be presented in a manner similar to that given in chapter 2. Emphasis will be on the analysis of those circuits that are quite different from the corresponding circuits in the ARN-7 and on the function of the two relays, *K*101 (loop) and *K*102 (antenna).

You should have no difficulty in tracing circuits in this particular schematic, but a few pointers may be helpful. The band switches (*S*107, *S*108, etc.) are shown on band 1, 100 to 200 kc. (The other three bands are: 200 to 410 kc, 410 to 850 kc, and 850 to 1,750 kc.) Both relays are shown in the OFF, or de-energized, position. The power control relay, *K*501, located in mounting MT-273, shows that the pilot's control box has control, and we shall use it in tracing circuits involving the remote-control box.

Note that each connector includes a male *P* plug and a female *J* plug. Each male plug terminal is indicated by a capital letter (*P*102A, *P*301J, etc.). Each female plug terminal is indicated by a number (*J*501-29, *J*302-31, etc.). Electrical conductors lead from the terminals to the various circuits.

We shall refer to individual conductors by the terminal letter or number, such as line K, line 30, etc. If the electrical contact is completed through a connector, we shall simply state the number, the letter, and either the male or female plug. For example, 41-S at *P*102 indicates we are tracing a circuit from terminal 41 in the mounting through the connectors *J*501-41 into *P*102S into the receiver unit. Line X enters a cable (heavy black line) and emerges as line S along the cable, ending at the third armature contact (from the solenoid) of the antenna relay *K*102. When the same circuit is traced in the opposite direction (from the receiver to the relay in the mounting), the conductor will be designated as *S*-41 at *J*501.

Since all electrical conductors are numbered or lettered the same at their respective ends, time will be saved in circuit tracing by looking for the line, letter, or number along the cable near the circuit that the line is to terminate. For example, the audio line to the MIKE jack at the control box is line W at *P*102; obviously, this line must terminate at the audio output circuits and thus line ***P***

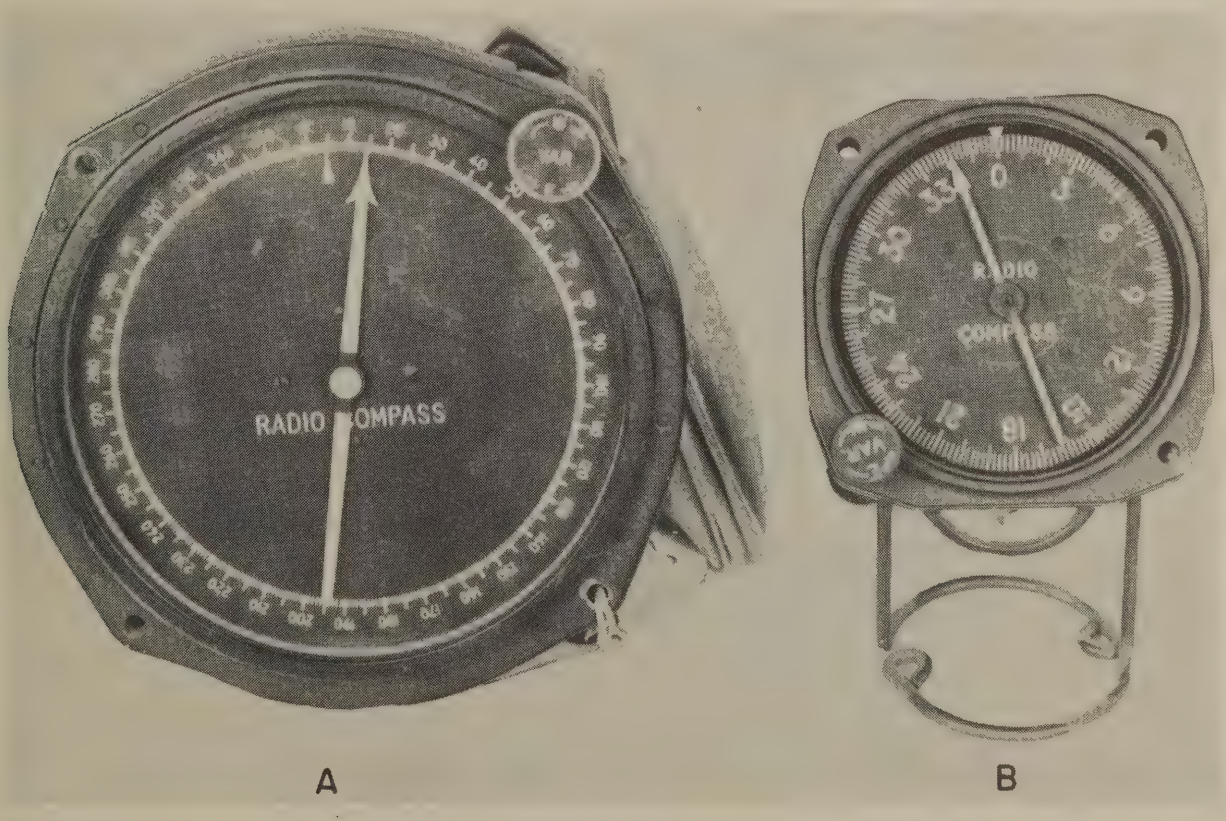


FIGURE 42. Indicators.
A. ID-92A/ARN-6 (Navigator).
B. ID-90A/ARN-6 (Pilot).

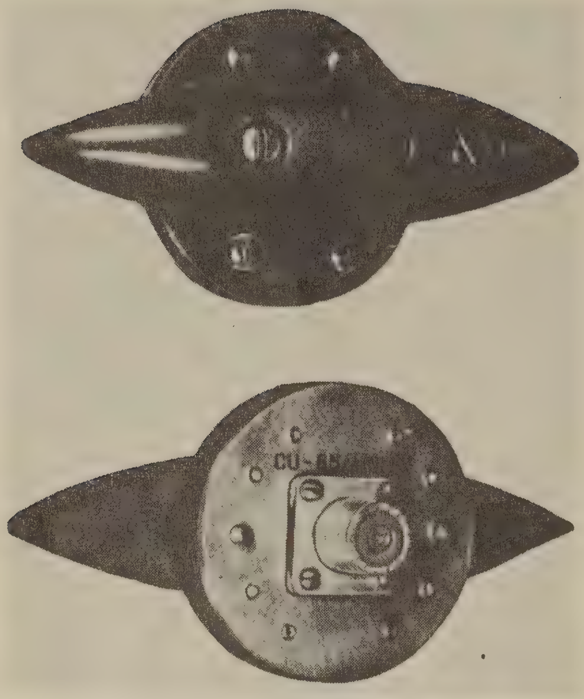


FIGURE 43. Coupling Unit CU–65/ARN–6.

can be quickly located at its terminal, which is the audio output transformer *T*105B (extreme upper right of schematic).

26. Antenna Operation

In ANTENNA position of the function switch, *S*305, the set is used for ordinary communications reception with the sense antenna. This involves the superheterodyne section of the set, including the tone-cw oscillator stage and the antenna relay, *K*102, which is energized.

Remote-control Box C–149A/ARN–6. The function switch, *S*305, is drawn schematically as five separate switches, each having four positions (shown set on COMPASS position). Actually, the switch is a rotary, two-wafer type. One wafer has twelve contacts. This is switch *S*305A (shown as four separate switches), the other wafer being the *S*305B section. The *S*305A sections cannot be confused, as each of the contacts that are actually used are numbered. Thus, the first or top section of *S*305 contains the active loop contact, 3A, and the rotating contact, 4A. The contacts (marked COMPASS and OFF) having no circuit connection are not numbered. The other switch sections are designated likewise.

With the function switch set at ANTENNA position, contact 6A of *S*305 is grounded through the rotating contact 8A. Contact 6A leads to *F*11 at *J*302. Line 11 at *J*302 emerges as line 11 at a fixed relay contact of the control change-over relay, *K*501.

On the armature side of the relay, the conductor is numbered 34 and leads to junction 34 in the mounting. This line ends at terminal 34 of *J*501, which connects to terminal R at *P*102. About 9 inches to the right of *P*102, the cable branches upward and line R branches off at the upper end to connect to one side of the antenna relay (*K*102) solenoid. This connects the solenoid to ground—the *A* side of the primary power source. (Note that the relay is partly shorted to provide the momentary high starting torque required to energize the relay.)

The other side of the coil connects to line G, which ends at terminal G of *P*102. Terminal N is simply a tie point, and *L*139 (65 henrys at 1,000 cycles) with a 0.25-μf capacitor, *C*1191, forms a heater filter in this common *A*+ lead. Continuing, line 49 at *J*501 leads to junction point 49 in mounting MT–273, then down to contact 49 in *K*501. (The relay contacts may be identified by the same number as the associated line.)

From the relay, line 10 leads to line L at *P*301, which connects to line J–31 at *J*302 through contacts 6B and 4B of switch *S*305B. Line 31 leads to junction 31 in the mounting. Follow heavy line 31, which angles upward to the right from junction 31 into the cable that leads directly to the positive (*A*+) 26.5-v dc primary power source at the left of the mounting.

This completes the primary power circuit of the antenna relay. The circuit was traced in considerable detail to help you to grasp quickly the tracing of circuits through the several units and interconnecting cables of this particular schematic.

Since terminals G and N at *P*102 are *A*+ terminals, it will be left to the student to follow the *A*+ lead, starting at the right side of heater choke *L*139 and following the *A*+ lines to all circuits to which they lead. In addition to the antenna relay, *A*+ voltage is continuously applied to all tube-heater circuits and also to the plate and screen circuits of the stages used for antenna operation.

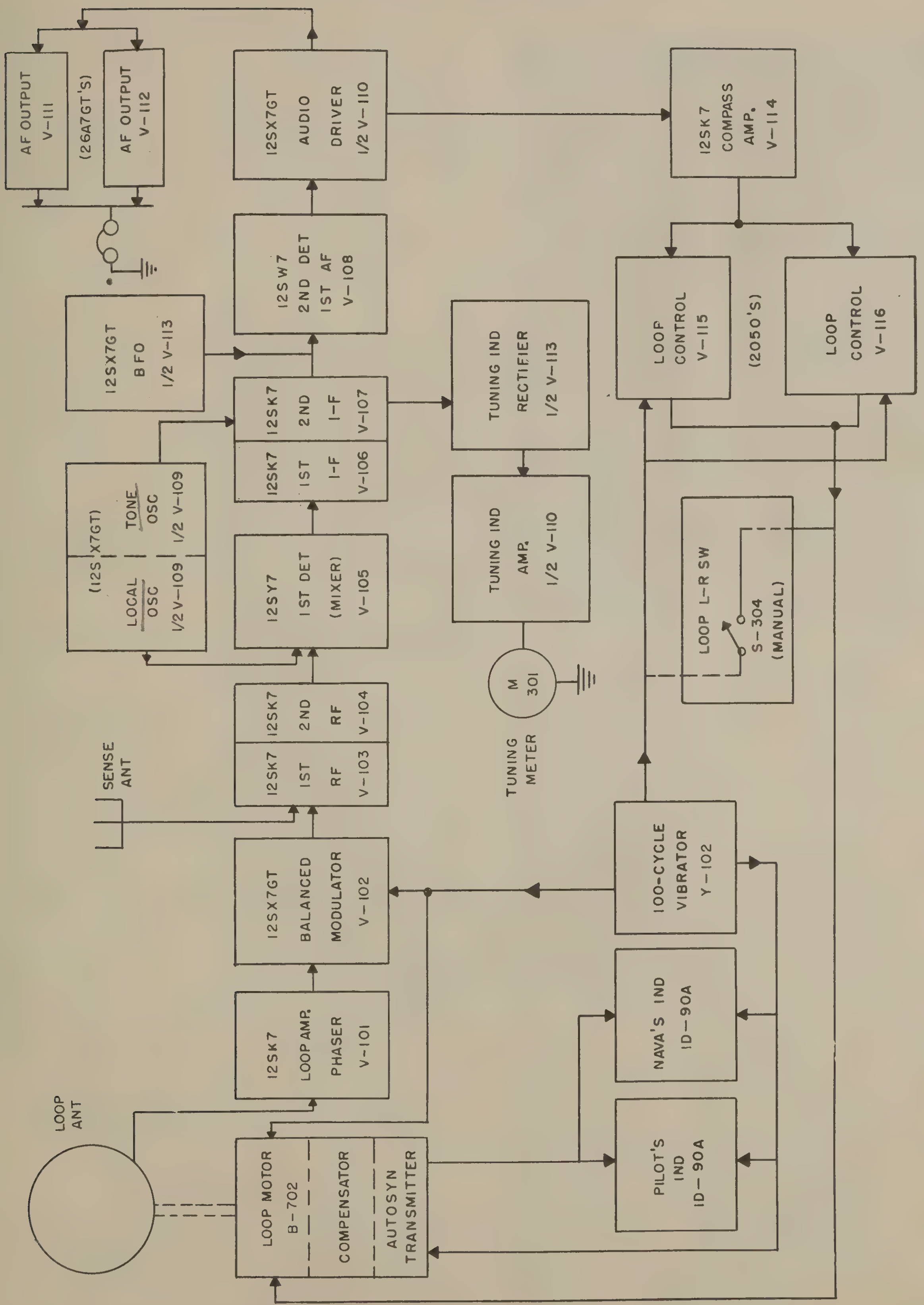


FIGURE 44. Functional Block Diagram.

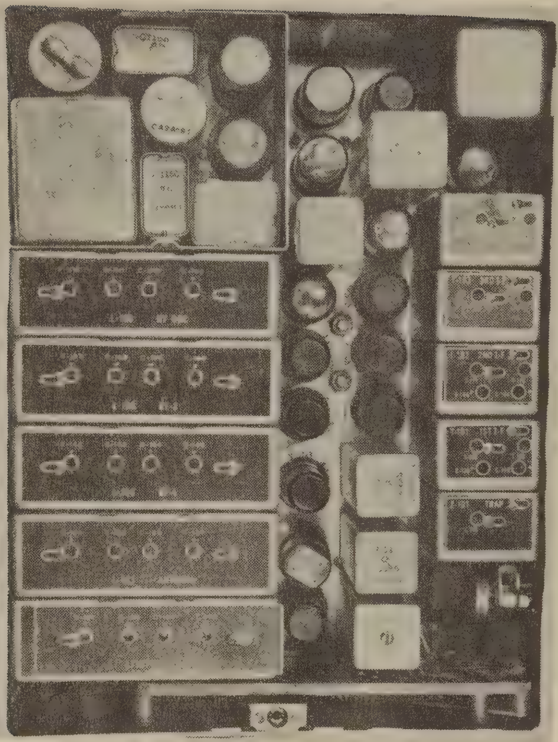


FIGURE 45. Top View of Radio Compass Unit R–101A/ARN–6 with Cover Removed.

The only other contacts of the function switch that are used on antenna position are 11A and 10A, which connect the tip of the MIKE jack, *J*301, to the audio line P in the receiver. The line from the jack is N–32 of *J*302, which is easily followed through mounting MT–273 to terminal 32–P at *P*102. The other functions of the remote-control box will be discussed as required.

Function of Antenna Relay *K*102. This relay is a rotary two-wafer type with a special contact arrangement. The rotor blades and the stator contact clips are made of a silver alloy. The tapped coil has a resistance of 7 ohms when operating and 225 ohms for holding.

The five rotors (rotor blades) of relay *K*102 are each connected to an *A*+ line. (For reference, number the rotors of *K*102—5 rotors—and *K*101 —11 rotors—in consecutive order from right to left starting at the coil.) The operation of relay *K*102 makes the following circuit changes (rotors 1 through 5 in order):

1. Removes short from holding-coil section to decrease current drain and prevent overheating.
2. Removes primary power (26.5 v dc) from the vibrator-inverter unit, *Y*101.
3. Switches cw-voice circuits from the tone oscillator, *V*109B, to the beat-frequency oscillator, *V*113A, by simply switching the *A*+ supply (indicated as *B*+ in the schematic when applied to plate or screen circuit) from one tube plate to the other. The circuit, however, is not completed until the cw-voice switch, *S*306, is closed in the control box.
4. Removes plate and screen voltage from the compass amplifier, *V*114. (Terminal 2 of af filter choke *L*107B—below tone-oscillator tank—is the common *B*+ or *A*+ point for the plate and screen voltage.)
5. Removes plate and screen voltage from the loop amplifier, *V*101, and modulator *V*102.

(*Note:* Since the schematic is the electrical blueprint of any piece of radio equipment, it bears repeating that proficiency in the greatest possible use of the schematic and knowledge gained therefrom comes only through constant practice in tracing circuits in the schematic. Therefore, all circuits mentioned or described in this chapter must be traced completely.)

27. Radio-frequency Section for Antenna Operation

This section includes the two rf stages, the first detector, and the two i-f stages. The sense-antenna signal is coupled to the input circuit of the first rf amplifier as follows: from the coupling unit CU–65 (located directly above the loop amplifier stage, *V*101) through *J*601, transmission line CG–405 (*R*104 is the static leak), last contact (No. 11) of *K*101, coupling capacitor *C*122 (*Z*101 i-f wave trap tuned to 142.5 kc is not used on band 1), past *S*104B, and on down to the primary coil used on band 1.

The signal is then inductively and capacitively (*C*132) coupled into the secondary, which is connected to the control grid through band-switch section *S*107A. *C*130 across the secondary is a trimmer. *C*134 is for temperature compensation. *R*114 and *C*129 are used for decoupling and avc filtering.

The variable tuning capacitor section is *C*111B. The entire tuning capacitor (*C*111) consists of five identical sections variable from 12.5 to 402$\mu\mu$f. The remaining four sections tune the following input stages: (A) loop amplifier, (C) second rf, (D) first detector, (E) local oscillator. It can be seen, then, that the rf tuned circuits,

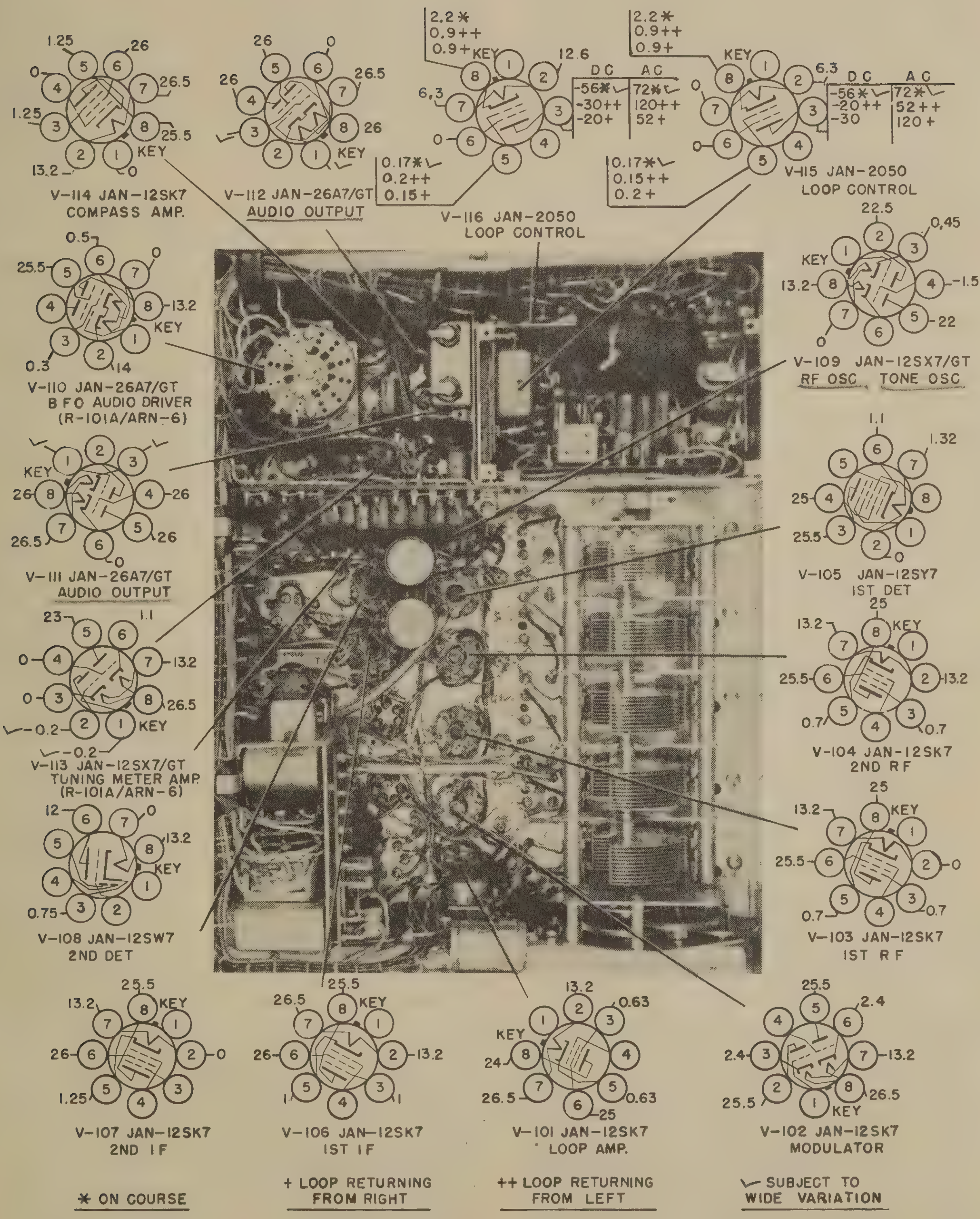


FIGURE 46. Bottom View of Radio Compass Unit R-101A/ARN-6 with Cover Removed.

band switches, etc., of the ARN–6 are quite similar to those of the ARN–7.

The gain of the first rf, second rf, and first detector stages is controlled by delayed avc voltage. In addition, the gain of these stages is also adjustable by sensitivity control *R*1101 on band 1. (This will be discussed more fully in connection with the receiver volume-control system.)

The local rf oscillator signal is injected in the first grid of the 12SY7 pentagrid mixer tube through coupling capacitor *C*1109. The signal is taken from the plate to i-f transformer *T*108 (455 kc on band 1) through a shielded line, making connection at terminal 7 of the i-f transformer assembly, *T*101. It is plainly shown in the schematic that the *T*101 assembly consists of two separate transformers (*T*108, *T*109), each with three windings, with the middle or tertiary winding used as a coupling link.

*T*109, used on the other three bands, is tuned to 142.5 kc. The proper transformer is selected by band-switch sections *S*112A (secondary) and *S*112B (primary). The i-f signal is coupled from the primary into the secondary of *T*108 through a third (middle) winding, which increases the selectivity and gain of the transformer.

The first and second i-f amplifier stages are typical circuits employing 12SK7 tubes operating with low plate and screen voltages (26.5 v dc) and proportionately lower bias and signal voltages, which, of course, applies to all stages in the set as previously explained. The bias for *V*106 (first i-f) is developed across *R*137, which is grounded through loop relay (*K*101) contact 5. For loop operation, however, *K*101 energizes, removing this ground and placing *R*184 and *R*1109 (threshold sensitivity control, which sets minimum bias or maximum rf gain) in the grid-bias circuit of the first i-f amplifier.

The output of *V*107 (second i-f) is fed into the primary of the third i-f transformer, *T*103, through switch *S*114B. The signal is inductively coupled into the secondary tuned circuit (top winding in *T*103 assembly) and fed to the second detector diode plate (pin 5 of *V*108) through *S*114A. The output of the BFO (455.9 kc on band 1 and 143.4 kc on bands 2, 3, and 4) is also coupled into this circuit through *C*1131, which is located in the oscillator circuit. The BFO is used for cw reception on antenna and loop operation. The pitch of the signal may be varied to suit the operator by very small motions of the tuning dial.

This also results in a better signal-to-noise ratio.

The i-f voltage developed in the primary tuned circuit (plate circuit of second i-f) is also applied to the avc diode (pin 4 of *V*108) through *S*114C and *C*199. The i-f component of the rectified avc voltage is coupled through *C*127 to the tuning indicator rectifier. (Suppressor-grid modulation and the silencing circuit associated with this stage will be discussed later.)

28. Audio-frequency Circuits for Antenna Operation

Second Detector and First AF Amplifier. The rectified current pulses in the second detector plate circuit (pin 2 of *V*108) develop the audio voltage across diode load resistors *R*~~[illegible]~~158, *R*181, and *R*125. These resistors in combination with *C*1100 and *C*1102 also serve as an i-f filter system. That portion of the af voltage appearing across *R*125 is applied to the grid of the triode through *C*1145 and the additional filter, *R*151 and *C*1106. The grid circuit is completed to the cathode through grid-leak resistor *R*183 and cathode-bias resistor *R*153.

Automatic Volume Control Circuits. The avc diode (pin 4 of *V*108) rectified voltage appears across the series load resistors, *R*148 and *R*146. The full avc voltage across these resistors is filtered through *R*147, *C*1105, *R*145, and *C*194 and then applied to the first rf amplifier (*V*103) grid circuit through the decoupling resistor, *R*114. That portion of avc voltage developed across *R*146 is filtered through *C*1104, *R*149, and *C*1103 and is applied through *R*119 to the grid of the second rf amplifier (*V*104) and through *R*127 to the signal grid (g_3) of the first detector, *V*105.

Actually, no avc voltage will be developed until the peak signal voltage on the avc diode plate exceeds the delay voltage (cathode bias) developed across cathode resistors *R*182 and *R*153 of *V*108. Since there is no avc until a certain minimum signal strength is reached, it is commonly called *delayed avc.*

Audio Driver and Output Circuits. The audio signal appearing at the triode plate of the first af amplifier is coupled through *C*1139 to the grid of the audio driver (*V*110A). The filter network formed by *C*1134, *R*171, *C*1135, and *R*169 removes any i-f still present in the audio signal. *R*168 is the grid-leak resistor, and *C*1133 is the plate bypass.

The output of the driver, *V*110A, is transformer-coupled by *T*105A to the audio output stage, which is two tubes (*V*111 and *V*112) connected in push-pull parallel. From each end of the secondary there is a capacitor (*C*1141 and *C*1178) connected to ground which bypasses the audio frequencies beyond the useful range to prevent any possibility of squealing. (*Note:* Triode plate current returns to cathode of *V*108 through input transformer of compass amplifier *V*114.)

The beam power audio output tubes are especially designed for operation with 26.5 volts on the plates. Operation of the tubes is Class AB_2 with a very low plate current that approaches cutoff. Grid current flow develops the proper bias across grid-bias resistor *R*172 bypassed by *C*1140. Thus, an automatic bias is developed which varies with the signal level and maintains the average operation of the tubes as Class AB_2. A parasitic suppression resistor is in series with each control grid.

The plates of the output tubes are connected to the push-pull primary of the output transformer, *T*105B, to limit the frequency response and to stop oscillations which might otherwise result, since the secondary is connected to a feedback network as well as to the audio circuits and to the headphone jack in the control box.

From terminal 8 of *T*105, to which audio line P is connected, another lead takes the audio voltage through a filter network (*R*165, *C*1138, *C*1137, *R*164, *R*163, and *C*1136) to the cathode circuit of the audio driver. The network is designed to pass 2,500 cycles per second, but its inherent sharpness of tuning is reduced by a low-impedance load consisting of *R*162 and *R*166.

These two resistors also act as a voltage divider; since *R*166 is in common with the cathode circuit of the audio driver (*V*110A), a feedback results. The effect of this feedback is to boost the high audio frequencies.

Audio and Sensitivity Controls (All Positions of *S*305). With the function switch (*S*305) set for antenna or loop operation, the receiver volume is controlled entirely by varying the rf gain of the first rf, second rf, and first dectector stages. This is done by varying the resistance between the cathodes and ground, which therefore varies the bias and gain. The actual resistors involved are *R*1104 (located below *R*132 in the cathode of the first detector stage), which is paralleled by the series combination of *R*1101 (threshold sensitivity control), and *R*302C, which is located in the control box and varied by the volume control knob.

To trace out the series combination to ground, start at the junction point located below the junction of *R*132 and *R*1104 and proceed as follows: through *R*1101, terminal 8 of band-change motor mechanism *B*101, and *S*128 (threshold sensitivity-control selector operated by the band-change motor mechanism) to terminal 7 of *B*101. This leads through audio choke *L*138 to terminals U–44 in *J*501, 44–18 in *K*501, and 18–H in *J*302. At the first junction in line H, follow down through *R*302C (volume control) out through the center tap to ground. (Line H also leads to an open contact associated with rotor 8A of *S*305A.)

The audio output circuit to the mike jack, *J*301, is traced as follows: starting at the *S* end of the secondary of af transformer *T*105B (*S* and *F* simply mean *start* and *finish* ends of the winding), trace to terminal 8 into line P, to terminals P–32 and *J*501, junction 32 in MT–273, 32–N in *J*302, and through contacts 10A and 11A of *S*305A to the tip of *J*301. With the headphone plugged into the jack, the circuit is completed to ground through the phones and sleeve of the jack.

It can be seen that this section of *S*305 also shorts *R*302A, *R*304, and *R*303. The variable tap of *R*302B ends in an open contact of *S*305A (rotor number 12A). On compass operation, these resistors (*R*302A and B, *R*303, *R*304) form a bridged-T attenuator and control the audio volume of the set. The rf circuits are then grounded through rotor contact 8A of *S*305A, which also shorts *R*302C.

As the schematic shows, the headset jack *J*301 is a closed-circuit type; that is, the *hot* side of the audio line continues from the tip through the closed contact to terminals M–17 of *J*302 and ends at junction 43 in the mounting. Generally, in the large aircraft, the output of the radio compass is connected to the intercommunication system from junction 43 in the mounting. This circuit is opened whenever the headphone plug is inserted in *J*301.

On bands 2, 3, and 4, threshold sensitivity control *R*1108 is switched into the rf gain-control circuit through the sensitivity-control selector switch *S*128, replacing *R*1101. Also, another

sensitivity control, $R1109$, in the cathode-to-ground circuit of the first i-f amplifier, $V106$, is used during loop operation to help keep the overall sensitivity of the set constant for each type of operation. (All sensitivity-control adjustments are made at the factory.)

Code Reception (All Positions of $S305$). Code may be received either by feeding the output of a BFO into the second detector (antenna and loop operation) or by feeding the output of a tone oscillator into the suppressor-grid circuit of the second i-f amplifier (compass operation).

The oscillators are placed in operation by relays $K101$ and $K102$, but the $A+$ line to the relays is controlled by the series cw-voice switch, $S306$, in the control box. When $S306$ is closed (cw position), $A+$ is applied to either the BFO or tone (900 cycles) oscillator plate circuits through the relays, depending on the position of the function switch. Voice and code may be heard at the same time, but with $S306$ open only voice can be heard.

29. Indicator Circuits

Tuning Indicator Circuit. Tuning meter $M301$ is a reversed-current type of meter (as in the ARN–7) with a full-scale current of 295 microamperes at no signal. The scale is marked with an arrow and the words TUNE TO MAXIMUM. The pointer swings to the right with decreasing current as the set is tuned.

The ripple (i-f) component of the rectified avc voltage is coupled through $C127$ to $V113B$, which is connected as a diode. The rectifier output appears across load resistors $R178$ and $R179$. The bias voltage across $R179$ is applied to the grid of the tuning-indicator amplifier ($V110B$) through filter $R177$ and ~~$C144$.~~ Tube $V110B$ is a dc amplifier, and its plate current is measured by $M301$. An increase in signal strength develops a higher bias voltage across $R179$, which reduces the current in $M301$ and causes the pointer to move to the right. Maximum dip of the meter pointer indicates proper tuning of the set.

Band-change Circuit (All Positions of $S305$). Motor $B101$, which operates the band-change motor mechanism, is a series motor and will run if either field is connected to the +26.5-volt dc source; the direction of rotation will depend upon which field is used.

The arm of band switch $S303$, located on the control box, is shown set at band 1. It is connected to the $A+$ source through contacts 6B and 4B of $S305B$. When $S303$ is moved to band 2, for example, the motor will rotate until the switching is complete. This is determined by the stop switch, $S126$, in the motor mechanism.

The circuit is traced from the arm of $S303$ ($A+$) as follows: K–6 of $J302$, contacts 6–24 of $K501$, 24–J of $P102$, and through line J to terminal 2 of $B101$. The electrical continuity to the right-hand field winding is completed through the sliding contacts of the upper half of the split shorting-ring segments of $S126$, then through the motor armature to ground at terminal 6. $S126$ rotates clockwise, so that when the open space (gap) shown occupied by the band 1 contact reaches the band 2 contact, the circuit is broken and the motor stops.

If $S303$ is now turned back to band 1, the other field winding of $B101$ is energized and the motor rotates in the opposite direction until the proper position is reached. The motor operates in this manner for every change of band switch $S303$. The successive positions of the mechanism are in the sequence 1-3-2-4 (lines H, K, J, L), which is used for better electrical and mechanical design of the rf transformer assemblies. This is plainly shown in the schematic of $S126$.

Whenever the band-change motor operates, a portion of the armature voltage is applied through $R100$ to the cathode of the second i-f amplifier, $V107$. This bias is sufficient to cut the tube off and is used to silence the receiver during the switching operation.

Control Transfer Circuit. Assume that the pilot's control box has control but that the navigator desires control to obtain a fix. The navigator can so inform the pilot over the *intercom* system, and the pilot will push the control button on his box, giving the navigator control. The navigator can himself gain control by setting the function switch on his control box to the ON position and pushing the control button.

The control button, $S301$, must be held down momentarily, so that relay $K501$, in mounting MT–273A has time to energize. This relay is a stepping type, such that successive impulses switch receiver connections alternately from one control box to the other. $S301$ simply completes one side of the $A+$ line to the relay solenoid

through contacts 4B and 6B of $S305B$. The other side of the solenoid is connected to ground through 30–Z of $P102$. Line Z may be traced to a fixed-ground junction near terminal 2 of the vibrator circuit.

The lower end of the solenoid of relay $K501$ is tapped and connected to terminal 36 in the mounting through a spring-type switch that is shown closed and is not connected to the stepping mechanism. Instead, it is operated by a lever on the shaft of the relay solenoid. When the solenoid is energized, the switch opens, cutting in a high-resistance section of the solenoid to prevent overheating in case the button should be pressed too long. $C501$ reduces sparking when $S301$ is opened. Upon operation of $K501$, all control-box connections are transferred, except the 26.5-volt supply, the audio output, and the ground connections, which are common to both boxes.

(*Note:* By this time, it should be clearly understood that to trace a circuit in the complete schematic, you may begin at any pertinent point, such as switch 1, connector, junction, or the tube socket. The important thing is to be able to follow the electrical continuity through the various units, cables, lines, and switches. If, however, it is necessary to determine the polarity across a circuit component, then, of course, the direction of electron flow must be observed.)

30. Loop Operation

With the function switch, $S305$, set at the LOOP position, the set is used for reception with the loop antenna. The loop relay, $K101$, is energized through $A+$ contacts 4B and 6B of $S305B$ and $A-$ contacts 5A and 8A of $S305A$. (Trace the complete $K101$ solenoid circuit, starting at grounded $A-$, arm 8A of $S305A$.)

The relay arms (rotor contact), listed in consecutive order from the solenoid, make the following circuit changes:

1. The first arm is a holding contact.
2. The second arm and its contact are not used.
3. This contact has no use in the energized position. It completes the $A+$ line to the BFO through arm 3 of $K102$.
4. Switches $A+$ from the tone oscillator plate to the BFO through the $A+$ contacts of $K102$.
5. Opens the ground line which shorted resistors $R184$ and $R1109$, two of the cathode-bias resistors in the first i-f stage, $V106$. This decreases the gain of the first i-f stage to decrease the noise level and tends to equalize over-all gain on loop operation with that on antenna and compass operation.
6. Grounds (short circuits) the primary of modulation autotransformer $T119$ (located below modulator $V102$), thereby removing the modulating voltage from $V102$. This method is used because the vibrator unit $Y101$ must be kept operating to furnish power for the loop-drive motor and indicator circuits.
7. An extra rotor contact through which the ground connection is made for arms 5 and 6.
8. Opens the ground line to the junction of $R108$ and $R109$ in the modulator cathode circuit, thus removing the short across $R108$. Tube $V102B$ now operates as a Class A rf amplifier for the loop signal, and V102A still remains at cutoff (as in the ARN–7 modulator—to review modulator theory, see chapter 2). The grid of $V102B$ is returned to the cathode essentially through $R109$. The +26.5 volts is applied at the junction of $R110$ and $R109$. This voltage will divide across $R109$ and $R108$ in proportion to the ratio of their resistance. Thus, about 5 volts appears across $R109$, biasing $V102B$ as Class A. The grid of $V102A$ is returned to cathode essentially through $R110$, across which appears the full 26.5-v dc or bias (increased slightly by conduction of $V102B$), thus cutting off this section of the modulator tube. (For compass operation, $R108$ is shorted as shown and both grids are returned through $R110$. The modulator then operates as a Class B push-pull amplifier.)
9. Ungrounds the cathodes of the loop-control tubes, $V115$ and $V116$, thereby preventing automatic loop operation.
10. Grounds antennna terminal 8 on the i-f trap, $Z101$, through capacitor $C110$. The capacitor simulates the sense antenna so that circuit conditions will be unchanged.
11. Disconnects and grounds the sense antenna.

31. The Vibrator Unit

The vibrator is properly called a vibrator-inverter because it changes dc voltage into ac voltage. Because the vibrator unit develops ac in a manner different from that of the corresponding ac source in the ARN–7 and because

it is pertinent to both loop and compass operation, you will now study in some detail its theory of operation and the purpose of its principal components.

The mechanical vibrator, *Y*102 (to the left of *Y*101 and not labeled in the schematic), is a plug-in subassembly of *Y*101. Physically, it appears as a tubular can 3 inches long and 1½ inches in diameter. It includes the components included within the dashed line in the schematic of the vibrator unit.

The circle symbol incloses the vibrating arm (reed or armature), the fixed contacts, and the armature coil (electromagnet). Dual contacts 1 and 2 on the left connect to one side of the center-tapped primary of vibrator transformer T107, and the right-hand contacts (5 and 6) connect to the other end. The remaining single contact is electrically connected to center-tap terminal 2 through ground.

When the function switch is set at LOOP or COMPASS position, *A*+ is available at terminal 9 of the vibrator unit. Primary power is applied at the same time to two vibrator circuits. Assuming that the vibrating arm is closed to the left contacts 1 and 2 as shown, the current in the first circuit would flow from ground through the center tap, up through the primary of *T*107 through the closed vibrator contacts, and down through *L*132, *L*108, and the shielded line to *A*+ terminal 9. The current increasing from zero in the *T*107 primary induces a voltage in the secondaries.

The current in the second circuit flows from ground through the armature coil, the vibrator arm, *L*132, etc., to terminal 9. The magnetic attractive force built up in the coil pulls the vibrating arm over to contacts 5 and 6, breaking the original two circuits. The collapsing field in the primary induces a voltage in the opposite direction in the secondary, completing half a cycle. With the arm at contacts 5 and 6, the current is reversed and momentarily flows down through the lower half of the primary of *T*107. A mechanical spring pulls the arm back to the original position. This make and break at contacts 5 and 6 completes the cycle of induced voltage in the secondary.

The rapid interruption and reversing (100 times per second) of a dc current through the primary inductance develops a distorted square wave of self-induced voltage and a distorted ac wave in the secondary. This necessitates considerable filtering in both the primary and secondary circuits associated with the transformer. In the primary, the filtering is necessary to prevent excessive arcing and burning of the vibrator points and to keep noise voltages out of the common dc line. The filtering in the secondary is used to eliminate noise voltages and to shape the distorted wave into a sine wave for the modulator.

In the primary circuit *L*108 is an af line filter choke, *C*1172 is an electrolytic noise filter in the input line, *L*132 and *C*1151 form an rf *hash* filter, and *C*1152, *C*1153, and *C*1154 are high-frequency noise filters. *C*1192 and *C*1193 are buffer capacitors across the vibrator contacts. They suppress the voltage surges that might otherwise damage the vibrator. The damping buffer of *R*1112 and *C*1168 across the primary provides additional protection.

At the top secondary, from terminal 6 the noise filter consists of *C*1156, *R*189, and *C*1171. From terminal 5 the noise-filter components are C1157, L135, and C1170, and from terminal 4 they are *C*1158, *R*188, and *C*1169.

At the lower secondary, the noise-filter components are *L*133, *C*1162, *L*134, and *C*1155. At a junction near *L*133, the distorted 100-cycle voltage is applied through a filter (voltage phasing network) which shapes the wave into a pure sine wave of the modulator stage. The filter components are *R*185, *C*1159, *R*186, *C*1160, *R*187, and *C*1161.

The vibrator power transformer, *T*107, develops the following voltages across its windings:

Primary—53 volts peak;

Top (No. 1) secondary—174 volts rms at 50 ma, center-tapped at 87 volts;

Bottom (No. 2) secondary—54 volts rms at 100 ma, tapped at 22 volts at 400 ma between terminals 7 and 8.

The electrostatic shield, between the primary and the secondaries, is shown as a dashed line to ground in the schematic.

The secondaries are connected by their respective conductors to the following circuits:

Line C—right side of loop L-R switch *S*304 (at bottom of control box in the schematic);

Line E—high-impedance winding of the loop-drive motor *B*701;

Line B—left side of loop L-R switch;

Line F—low-impedance winding of the loop-drive motor;

Line D—Autosyn transmitter *B*702 and indicators.

(You will study the loop-control tube circuits in the section on compass operation.)

32. Loop-control and Indicator Circuits

The loop-drive motor is manually controlled through the loop L-R switch, *S*304, in the pilot's control box. The loop motor is a capacitor-start, 2-phase ac motor (theory of operation is the same as for motor MO–18A in the ARN–7). Owing to the phasing capacitor, *C*1150B (located near terminal 8 line F at *Y*101), the current through the low-*Z* winding is 90° out of phase with the current through the high-*Z* winding.

When operated, the L-R switch, *S*304, simply connects the high-Z winding to the 100-cycle source voltage through ground, causing the loop motor to rotate. In the schematic, the upper arm of *S*304 is grounded through closed contacts 9A and 12A of *S*305A, and the lower arm shorts damping resistor *R*307.

To trace the complete ac circuit through the high-*Z* winding of the loop motor, assume that the switch is closed to the right side of *R*306. The circuit is then traced as follows: from ground through *R*306 to terminal X–14 at *J*302, 14–39 at *K*501 (junction 39 in MT–273), 39–C at *P*102, and then through line C to terminal 5 at *Y*101, to terminal 6 of *T*107 secondary, and out through center-tap terminal 5 to terminal 7 and into line E to the connector; continue with line 21, which leads into junction 21 at the mounting; follow the line leading up from the right scale of junction 21 to 21–G at *P*701, which connects to terminal 3 of the high-impedance winding.

The other end of the high-Z winding (terminal 4) is completed to ground through terminal A–2 at *J*405; line 2 leads to junction 2 in MT–273 and to 2–X at P102; line X leads to the actual ground point at terminal 2 of the vibrator unit, *Y*101, which completes the high-*Z* circuit, thus causing motor rotation to the right.

Returning now to junction 21 in the mounting, trace the remaining circuit through *K*501 to junction 27. Line 27 leads to 27–T at *J*302. This leads through *R*307 (the lower arm of *S*304 opens whenever the switch is operated) to *A*+. Thus, a very small damping current is applied to the high-*Z* winding of the motor to act as a brake on the loop.

The variable resistor (rheostat), *R*306, operated by the L-R switch varies the speed of loop rotation. It is designed with a special taper. For the first 6° of rotation, the full 15 k-ohms is in the circuit but drops to 2,500 ohms at 30° and to a minimum of 300 ohms at the stop. The current through the resistor may vary from a maximum of 40 ma to a minimum of 20 ma.

It can be seen that if left rotation is desired, the other half of the secondary winding (terminals 4 and 7) of *T*107 provides the power for the high-*Z* winding. Since the instantaneous polarity across the secondary is 180°, the phase of the current is shifted 180° as compared with the current phase for right rotation. At any instant, the current in the low-*Z* winding either leads or lags the current in the high-Z winding by 90° (owing to *C*1150B, as explained above). Assuming that the high-*Z* current is lagging the low-*Z* current during right rotation, then because of the 180° phase shift, it will lead the low-*Z* current during left rotation.

The remote-control indicator system (Autosyn or synchro system) operates in the same way as that of the ARN–7 (see chapter 2). Briefly, the three rotors are electrically connected in parallel to the 100-cycle source voltage at *T*107. The generator (*B*702) rotor is geared to the loop motor, and the indicator rotors are free to rotate except that mechanical damping is provided through a flywheel to prevent oscillation.

Each of the three stator windings (*B*702, ID–90A, ID–92A) consists of three Y-connected coils (ϕ_1, ϕ_2, ϕ_3) with their corresponding leads connected. If the rotors are alined in the same relative positions, then the corresponding stator coils will have equal and opposite induced voltages and no current will flow. If, however, the generator rotor is turned mechanically so that it no longer corresponds to the position of the indicator rotors, then equal voltages no longer exist between corresponding stator coils, and current flows in the stator windings. The resulting flux fields exert a torque on the rotors. The generator rotor is held mechanically, but the rotors of the two indicators turn until they are alined again with the generator rotor, thus indicating the loop position.

33. Compass Operation

In the COMPASS position of the function switch, the additional stages required for automatic loop control are placed in operation. This includes the compass amplifier, *V*114, loop-control tubes *V*115 and *V*116, and the modulator stage, *V*102, which operates as a Class B push-pull amplifier. The required circuits are completed through the de-energized contacts of the loop and antenna relays (position shown in the schematic).

As in the ARN–7, the voltage from the loop is amplified and retarded 90° so that is is either in phase or 180° out of phase with the sense-antenna voltage, depending on which edge of the loop is nearer the transmitter. The signal is fed in parallel to both grids of the balanced modulator (*V*102). Since the plates are connected in push-pull, the signal would ordinarily cancel in the plate circuit, but the 100-cycle modulating voltage from *T*119 is applied to the grids in push-pull, which makes first one of the triodes pass the signal and then the other. In effect, the loop signal is amplitude-modulated and its phase reversed in each half of the modulator tube.

When both halves of the modulator output are combined with the sense-antenna signal in the grid circuit of the first rf amplifier, the amplitude variations in the resultant signal will be either in phase or out of phase with the 100-cycle synchronizing voltage, depending on whether the transmitter is to the right or left of true null. (Review balanced modulator input and output wave forms in chapter 2.) The resultant signal passes through the rf and i-f stages. When it is finally demodulated by *V*108, the phase relation of the resulting 100-cycle audio signal with respect to the original 100-cycle modulating signal will be the same, that is, in phase or 180° out of phase as explained. (The modulating or synchronizing voltage is also applied to the loop-control tube plates as in the ARN–7.)

Capacitor *C*1108 couples the 100-cycle audio signal from the cathode circuit of *V*108 to the grid circuit of the compass amplifier, *V*114, through the tuned input autotransformer, *T*106A (not labeled in schematic). *C*1147 resonates the transformer at 100 cycles. The output transformer (T106B) is likewise resonated to 100 cycles by *C*1146. *R*196 and *C*155 form an rf filter in the grid circuit.

From the output circuit of *V*114, the 100-cycle signal is taken to the grid circuits of the loop-control tubes (*V*115 and *V*116 gas thyratrons) through *C*1148 and the shielded interconnecting cable. Since the signal is fed in parallel to the grids of the loop-control tubes, both grids will be either positive or negative at the same time. The plates being fed in push-pull from the 100-cycle source (*T*107) will be alternately positive and negative. One or the other of the control tubes will fire when its grid and plate go positive at the same instant. This, of course, depends on the phase relation of the synchronizing voltages, as explained in the preceding paragraphs.

The loop-control tubes simply replace the loop L-R switch and associated rheostat *R*306. Therefore, the firing of either control tube (*V*115 or *V*116) causes current to flow in the high-*Z* winding of the loop-drive motor. In effect, the conducting tube connects terminal 4 or 6 of the *T*107 secondary to ground, thus completing the high-*Z* circuit in the same manner as the L-R switch. (The cathodes of the loop-control tubes are grounded at contact 9 of *K*101.)

The phase of the current drawn determines the direction of rotation of loop-drive motor *B*701 and is, in turn, determined by which half of the secondary winding of *T*107 is used. Since this selection is made by the control tubes and therefore by the direction of the incoming signal, the motor turns the loop one way or the other, depending on which side of the loop is nearer the transmitting station. Rotation stops for lack of a signal when the *front* face of the loop exactly faces the transmitter. (If the back side of the loop faces the transmitter, it will be very unstable and any slight change from exact null will start the loop turning until it is properly oriented.)

In studying the loop-control tube circuits, note that the tubes are operated as triodes. The screen grids are grounded and act only as shields. *R*194 and *C*1173 are the common cathode-bias resistor and filter. *C*1167, *R*193 and *C*1166, *R*192 form grid rf filters for *V*115 and *V*116, respectively. *R*190 and *R*191 are plate current-limiting resistors, *C*1164 and *C*1165 are plate bypass capacitors, and *L*136 and *L*137 are the plate noise-filtering chokes.

To provide a suitable control for hunting of the loop (small oscillations about its null point) a negative feedback system is provided. The 100-cycle voltage applied to the high-*Z* winding of

*B*701 is also applied to voltage-dividing system *R*170 and *R*1105 (hunting control). The feedback voltage line may be traced from terminal 7 at *J*102 in the vibrator unit *Y*101 through the jumper to terminal 10, then through *R*170 and *R*1105 to ground. (*C*1150*A*, connected to terminal 10, is the small section of the loop-motor phasing capacitor, which is in shunt with the high-*Z* winding.)

The portion of the voltage selected by the setting of *R*1105 is attenuated and filtered by the R-C network, *R*1100, *C*131, *R*1106, *C*140, and *R*1102. The output from this network is applied to the grid of *V*114 along with the signal from the second detector. Since this feedback signal is negative, it tends to counteract the original signal. In practice, the strength of the feedback voltage is increased by adjusting *R*1105 until the hunting just stops. The adjustments are made under standard test conditions with a signal strength of one-tenth volt per meter.

34. Testing and Troubleshooting

It is admittedly impossible to troubleshoot without the actual equipment; however, "thinking through" and visualizing some of the causes for equipment failure and the test made to localize the particular trouble will be of benefit. You must, of course, keep in mind that the schematic does not show the physical layout of the parts in the chassis. For example, it may be necessary to make a meter check between two resistors that appear to be widely separated in the schematic, whereas in the set they may be mounted an inch apart on an easily accessible terminal board.

In the following discussion, assume that the radio compass set is being tested at a repair station and that all the electronic tubes are OK. (Always check tubes first as a cause for failure.)

Unless it is obvious that the trouble is in a circuit used only on compass operation, it is best to test the operation of the set first on the ANTENNA position of the function switch, followed in turn by the LOOP and COMPASS positions. For voltage checks, the receiver is removed from the mounting in order to expose, in the mounting, the terminals from which voltage and continuity tests are made.

The receiver is reconnected to the mounting through a special extension cable (CX–1021/ARN–6) designed for that purpose. The tube-socket voltages are measured with the function switch in COMPASS position. For accurate readings, a 20,000-ohm-per-volt voltmeter or a vacuum-tube voltmeter is recommended. (See fig. 46 for tube-socket voltages.)

Normal tuning-meter action indicates that the rf and i-f sections of the receiver are working properly, with the possible exception of the secondary of the third i-f transformer. After a warm-up period of about 30 seconds, the tuning-meter pointer should swing to the left side of the scale. If the tuning-meter pointer remains against its clockwise stop, switch to the other position and check that tuning meter. If both tuning meters are inoperative, then continuity checks of the wiring in the tuning-meter circuit are necessary.

Also check the socket voltages of the tuning-meter amplifier tubes (*V*113B and *V*110B). If the tuning-meter action appears to be normal, apply a 10-microvolt signal, modulated 30 percent at 400 cycles, to the antenna through a 50-micromicrofarad capacitor. Turn the volume control fully clockwise. The tuning-meter pointer should swing about one scale division to the right as the receiver is tuned to resonance with the input signal.

Low Receiver Output, Antenna Operation—All Bands. When both signal and noise output are low or absent, first check all cord and cable connections for security or possible damage. Check for dc input voltage (+26.5 v) at binding posts 31 and 49 in the mounting. If the voltage is incorrect, check the cabling between the receiver mounting and the control box for possible open-circuit or high-resistance connections. Also, check the *K*501 relay contacts. Check the filtered dc voltage (26.5 v) across electrolytic filter capacitor *C*1127 (located above the first i-f transformer *T*101 in the schematic); if low, check *L*107B (above and to the left of C1127 in the schematic) and *C*1127.

If the dc voltage is OK and the tuning meter operates normally, then the trouble may be in the audio circuits. Test the socket voltages of the audio tubes (*V*108, *V*110, *V*111, and *V*112). If the readings vary considerably from the typical values in figure 46, check the wiring and components associated with the tube elements in question. Apply a 400-cycle tone from a signal generator, through a 25-microfarad capacitor, to the grid (pin 2) of the first audio tube, *V*108. A

signal input of 0.05 volt should result in an output of 50 milliwatts at the phone jack *J*301. Since

$$P_o = \frac{E^2}{R},$$

where P_o is the power output in watts, E is the effective ac voltage, and R is the load resistance, and the output load for the ARN–6 is 300 ohms, substituting the 300-Ω load and converting to *milliwatts* gives the power output as

$$\frac{P_o}{1{,}000} = \frac{E^2}{300}$$

$$P_o = \frac{10E^2}{3}$$

Solving for E when $P_o = 50$ milliwatts gives

$$50 = \frac{10E^2}{3}$$

$$10E^2 = 150$$

$$E^2 = 15$$

$$E = \sqrt{15}$$

$$= 3.87 \text{ v}$$

and when $P_o = 12.5$ milliwatts, E equals 1.94 volts. An audio signal of 0.27 volt applied to the grid (pin 4) of the audio drive *V*110 should also result in a 50-milliwatt output. If these checks show weak or no output, then the signal must be traced with a signal tracer or vacuum-tube voltmeter as it passes through the plate and grid circuits of the audio output stage, the audio driver, and the first af amplifier. Check all components in the circuit where the signal is weak or lost completely.

Should tests indicate that the cause for weak output is a defective i-f transformer or some component within the i-f circuits, then complete realinement of the i-f stage will be necessary. Also, it is sometimes necessary to adjust trimmers and tuning slugs when an i-f transformer or components are alined within a transformer assembly or completely to realine the set.

It is beyond the requirements of your present study to give you the rather lengthy step-by-step alinement procedure. If you are assigned to a maintenance activity on the AN/ARN–6, you will have access to the handbook of maintenance instructions, TO AN16–30ARN6–3, in which the alinement procedure as well as a more complete coverage of testing and troubleshooting is given. Repetition of the same detailed technical order material is deemed unnecessary.

Local (RF) Oscillator Tests. If the receiver is badly off calibration or inoperative, the difficulty may be traced to the rf oscillator (*V*109A). If socket voltage tests don't reveal the trouble, make the following tests:

1. Make certain the oscillator is oscillating on all bands by checking the grid-leak bias voltage on the grid (pin 4) with a vacuum-tube voltmeter. This should be about −2 volts with the set tuned to the high-frequency end of each band. If the tube is not oscillating, the grid voltage will be about −0.3 volt. If the oscillator is intermittent only on parts of one or two bands, try changing the oscillator tube (some tubes may test OK but will still not oscillate properly). If this doesn't correct the trouble, then a complete check of the circuit components, wiring, and switch contacts is necessary.

2. If the stage is oscillating but it is impossible to calibrate the dial at the high-frequency end of the band with the trimmer capacitor, check the shunt capacitor in parallel with the trimmer for a possible open circuit. If the low-frequency dial calibration is impossible with the transformer-core (slug) adjustment, check the series padding capacitors, *C*1121, *C*1118, *C*1119, and *C*1120. Also, check switch contacts on *S*124 and associated wiring. (If tube *V*109 or the circuit components are replaced, it will usually be necessary to aline completely all bands of the local oscillator and rf amplifier circuits. This information is given in TO AN16–30ARN6–3.)

Radio-frequency Amplifier Tests. The sensitivity of the radio-frequency section (rf and i-f) is tested in the usual manner by applying a modulated signal to the grid (pin 4) of *V*103. The standard 50-milliwatt output should be obtained with about an 8-microvolt input. If the i-f stages are OK but the sensitivity is low, one of the rf bypass capacitors, *C*129, *C*150, or *C*165, in *V*103, *V*104, or *V*105, may be open. If one of these capacitors is open, the rf ground will be removed from the grid return of the associated circuit and poor sensitivity will result. (It may also be necessary to check the gain in each stage.)

Another of the more common causes of poor sensitivity or high distortion on strong signals is a defective avc circuit. Normal avc action is checked as follows: Apply a 0.22-volt, modulated 455-kc signal into the grid of the second i-f tube,

*V*107 (band switch set at the 100–200-kc band and volume control at maximum). A vacuum-tube voltmeter should measure about −3 volts of avc voltage at the grid (pin 4) of the first rf tube, *V*103.

If there is no avc voltage, check the avc voltage at the diode (pin 4) of the second detector, *V*108. If it is not present, check coupling capacitor *C*199. If the voltage is present at the diode, then it will be necessary to check all capacitors and resistors associated with the avc circuit. If avc voltage is missing at one of the three controlled tubes, check the rf bypass capacitor and filter resistor in the defective circuit, that is, *C*129 and *R*114 in the first rf amplifier circuit.

Noisy Receiver Operation. To locate the cause of noisy receiver operation, check the following components for possible source of trouble: microphonic or shorted tube elements or shorted socket connection, loose wires or defective resistors or capacitors in the receiver circuits, poor contacts or high-resistance shorts in plugs and receptacles, corroded or damaged connections in the loop assembly, defective vibrator or hash filter in the vibrator unit, loose antenna lead-in in the antenna coupling unit, dirt between plates of variable capacitors, dirty contacts in switches and relays, loose bonding connections, and loose or corroded cable connections or fuses in the power source.

No Loop Rotation on Compass Position. Having checked for satisfactory operation of the set on ANT and LOOP and loop rotation with the loop left-right switch, proceed as follows: Bridge a 0.25-microfarad capacitor between the junction point of *R*150, *R*181, and *C*1102 (second detector circuit) and either terminal lug of capacitor *C*117 and to the right when connected to *C*118 (modulator circuit). If this test causes the loop to rotate OK, check the modulator input circuits and the switches and windings in the antenna transformer assembly, *L*103.

If the loop does not rotate when the bridge is applied, then check the output of the modulation transformer, *T*119, for the 100-cycle modulating voltage. This check is made between ground and the terminals of *C*117 and C118. If no modulation is present, check for possible shorts in *T*119, *K*101, or phasing capacitors *C*1159, *C*1160, and *C*1161 (in *Y*101). Also check for a possible open circuit of *R*187, *R*186, *R*185, or connecting wires.

If the modulating voltage is correct, proceed as follows: Bridge a short-circuiting jumper from terminal 8 of the compass-amplifier output transformer, *T*106B, to terminal 4 on the vibrator unit terminal strip. The loop should turn to the left. Change the jumper to terminal 5 on the vibrator terminal strip, and the loop should turn to the right. If the loop does not rotate when this check is made, turn the set off and make an ohmmeter check between cathode pin 8 of *V*115 and ground. The resistance should be about 47 ohms. If not correct, check *R*194 and contacts on *K*101. Also check the loop-control tubes' plate-circuit components.

Should the loop rotation be satisfactory, proceed as follows: With the set turned off, remove the vibrator, *Y*102, and tube *V*115 (*S*306 at COMPASS position). Apply a 100-cycle signal from an audio generator between ground and the junction point of *R*150, *R*181, and *C*1102 (below tube *V*108 in the schematic). Trace the presence of the signal with a vacuum-tube voltmeter on the grid and plate of *V*114 and the grids of the loop-control tubes, *V*115 and *V*116. If the signal is not present at one of the above test points, check all the components in the circuit between the point where the signal was present and the point where it disappeared.

Since the vibrator (*Y*102) develops the synchronizing voltage and power for the loop-drive motor, it must be in good operating condition if the set is to function properly on the LOOP and COMPASS positions of the function switch. If the vibrator is operating, a buzzing sound will be heard. If the vibrator is not working, replace with one known to be good.

The vibrator frequency and output voltage wave form are very important for proper automatic compass operation. A change in these factors beyond the design limits will cause the loop to rotate to bearing slowly on all bands. This may mean worn and pitted points or vibrator off frequency (the frequency must be 100 cycles ±5 cycles). In any case, always change the plug-in vibrator.

If this does not correct the trouble, then check the circuit components in the vibrator power supply and in the receiver which cause proper phase-shifting and filtering of the 100-cycle voltage applied to the modulator grids. The input (square wave) and output (sine wave) wave forms

to the phasing network in the vibrator unit are easily checked by means of an oscilloscope.

Testing and Maintenance Equipment. For complete inspection and overhaul at a depot shop, a standard radio compass test cage should be available. This is usually a screen-inclosed (shielded) room, with an rf of known field strength at the receiving loop position. It also supplies the sense-antenna signal through a 50-micromicrofarad capacitor.

Usually, the test cage has a complete setup known to be in good working order. Suspected components can be substituted into the good setup and good components into the equipment under test. This is a practical way to locate troubles quickly and get the set back into working order in minimum time. The test cage is required for over-all performance tests and should be used for complete alinement.

The following pieces of equipment are generally found in a well-equipped test cage.

1. Radio-frequency signal generator used for directly applied signals. It should have a frequency range from 100 kc to 2,500 kc and be capable of 30 percent modulation at 400 cycles by an internal or external modulating voltage. (External modulation is required for testing the vibrator.)
2. Output ac voltmeter calibrated to read directly in watts for a given load resistance. A convenient form is the I–166 volt-ohmmeter.
3. Vacuum-tube volt-ohmmeter, a 20,000-ohms-per-volt meter and a 1,000-ohms-per-volt meter. (For most readings for troubleshooting purposes, the less sensitive 1,000-ohms-per-volt meter will do.)
4. Tube tester; the I–177 is recommended.
5. *Q*-meter, required only for analysis of rf and i-f coils.
6. Any good quality general purpose oscilloscope, which is used in checking the loop-control system.
7. Audio signal generator.
8. Miscellaneous items, which include the special purpose cable, CX–1021/ARN–6, a watch with a second hand for timing the speed of the loop rotation, touch-up enamel, glyptal, and the usual service tools.

Summary

The AN/ARN–6 is essentially the same as the AN/ARN–7, but is smaller and lighter. The principal difference is in the power supply: a 100-cycle vibrator furnishes all ac voltage, and the primary dc voltage from the aircraft's CPS is applied directly to the plates of the amplifier tubes.

The AN/ARN–6 has the same stages as the AN/ARN–7, although different tubes are used, and the same types of operation—antenna, loop, and compass. It operates on the same four frequency bands, from 100 to 1,750 kc.

The AN/ARN–6 has proved to be a rugged, reliable radio navigation instrument. Like all electronic equipment, however, it requires periodic inspection by competent radio technicians to keep it in perfect operating condition.

REVIEW QUESTIONS

The following questions are study aids. Your answers are not to be submitted to the USAF Extension Course Institute for grading. Correct answers will be found at the end of this text.

1. Why is it necessary to use a special adapter to make voltage measurements in the AN/ARN–6?
2. On what bands is the i-f trap in the antenna circuits effective?
3. How is the receiver unit connected to the remote-control units?
4. Give the physical location and description of connector *P*102.
5. What is the essential difference between the Autosyn motors of the ARN–6 compared with those of the ARN–7?

Questions 6 through 12 inclusive are to be answered with reference to figure 44.

6. Name the stages required for antenna operation (voice reception).
7. What additional stages are required for loop operation?

8. Name the two stages used specifically to operate the tuning meter.

9. Name the additional stages required for automatic control of the loop.

10. Name the oscillators required for code reception.

11. List the commercial number and proper names of the different tubes used in the AN/ARN–6.

12. Name the various circuits and devices to which the 100-cycle ac power from the vibrator is applied.

Questions 13 through 19 are on ANTENNA position of the function switch—refer to text and complete schematic.

13. List the reference number and names of the tubes in pairs whose heaters are connected in series across the 26.5-volt primary dc source.

14. What two terminals in the mounting are used as the $A+$ and $A-$ terminals, respectively?

15. Explain how the function switch causes the antenna relay to energize.

16. Give the function of rotor contact 3 in relay *K*102.

17. What section of the tuning capacitor (*C*111) is used to tune the rf (local) oscillator? What is its capacitance range?

18. List, in the order given, the following components: first af (*V*108) plate load, audio driver (*V*110A) grid load, and associated coupling capacitor.

19. What is the purpose of the feedback circuit between the audio output and driver stages?

20. How is the audio output of the set controlled in compass operation?

21. What is a reversed-current type of tuning meter?

22. Trace the band-change motor circuit electron flow when the band-change switch, *S*303, is set to band 2.

23. What precaution is taken to prevent the change-over relay (*K*501) solenoid from overheating if the control push-button is held down too long?

24. What is the function of contact 5 in the unenergized position of *K*101?

25. How does the vibrator change dc to ac?

26. What is the purpose of the voltage phasing network that is connected to the secondary at terminal 9 of *T*107 through filter choke *L*133?

27. How is the current through the low-Z winding of the loop-drive motor shifted 90°? Why is this necessary?

28. Do the loop left-right switch and the loop-control tube perform different functions? Explain.

29. What is the relationship of the voltage and current in the stator (field) windings of the indicator system at zero torque and when torque is present?

30. What determines which control tube will fire?

31. How is the hunting of the loop reduced to a minimum?

32. What section of the receiver can be checked by observing the operation of the tuning meter?

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Handbook of Maintenance Instructions for Radio Compass AN/ARN–7. AN16–30ARN7–3.

ANSWERS TO REVIEW QUESTIONS

CHAPTER 1

1. Heading is defined as the direction in which an aircraft is pointed. It is measured as the angle, in degrees clockwise, which the longitudinal axis of the aircraft makes with some reference line such as true north or magnetic north.
2. True heading is the angle that the aircraft's longitudinal axis makes with a reference line extending from the aircraft through the geographic north (true north) pole. With magnetic heading, the reference line extends through the center of the earth's magnetic field.
3. The magnetic compass must be corrected for deviation and variation to obtain the true heading.
4. Compass heading is the angle which the direction of flight of the aircraft makes with an uncorrected compass in a particular aircraft. When the compass heading is corrected for deviation, it is called magnetic heading.
5. The amount of deviation is added to correct for easterly deviation, thus giving the correct magnetic heading.
6. To obtain the true heading, the westerly variation is subtracted from the magnetic heading.
7. The compass rose is a scale of degrees included with the compass, which is used to measure the angle from the lubber line.
8. An aircraft's position may be determined by landmarks, celestial navigation, dead reckoning, and the radio compass.
9. The operation of the radio compass depends mainly on the characteristics of the loop antenna.
10. At the null point, the plane of the loop is perpendicular to the direction of wave travel.
11. The null or minimum point is used because the loop is much more sensitive to any slight change from this *in-line* position than it would be if the maximum position (edgewise to the radio wave) were used.
12. The phase is shifted 180° when the loop rotates past a null point because the other side of the loop will be near the signal source. The induced voltage in this side will predominate and cause the resultant current to flow in the opposite direction through the antenna transformer, thus shifting the phase (instantaneous polarity) 180°.
13. Radio range stations transmit low-frequency directed radio waves that form a criss-cross pattern of radio airways throughout the United States and Canada. These directed radio beams are picked up by radio compasses and similar devices in aircraft and followed to their source. Thus, the radio range system forms a system of invisible air highways by which an aircraft can fly from one point to another.
14. The bisignal zones are regions of overlapping on each side of the four on-course lanes where both the *A* and the *N* signals can be heard, but one is stronger and predominates, depending upon whether the aircraft is to the right or left of the on-course lanes.
15. The cone of silence is an area the shape of an inverted cone located directly above the radio range station where the four courses intersect and within which practically no signal is heard.
16. The Adcock system employs five towers and two transmitters, which make it possible to transmit voice and range signals at the same time. In the 4-tower system, the range signals must be suspended while voice broadcasts are being made.
17. The pilot knows when he is over the radio range station because a 75-megacycle transmitter (Z marker beacon) is used to send an unkeyed signal vertically into the cone of silence. The carrier is modulated with a 3,000-cycle note which causes a light on the pilot's instrument panel to flash when the aircraft is over the station.

18. A *Radio Facility Chart* is a publication consisting of charts showing the location of radio ranges and the radio airways for the United States and parts of Canada. It contains all necessary information concerning radio range facilities. It is used in the preparation of flights, and a copy is kept in the aircraft at all times.

CHAPTER 2

1. The primary power required by the R–5/ARN–7 is 24–28-volt dc and 115-volt, 400-cycle ac.

2. The ALIGN mark will appear when the dial is rotated to the low end of band 4 (850–1,750 kc).

3. There are 19 lines connecting the remote-control box to the junction-box relay. The circuits associated with the following lines are T–58, power input relay RE–8; G–40, band-change meter; L–4, rf gain control; B–1, audio output; S–28, loop L-R switch.

4. The primary dc circuit is protected by a 5-amp fuse connected between terminals 61 and 60 of the junction box, and the 400-cycle ac is protected by a 3-amp fuse connected between terminals 50 and 49.

5. The lines from the junction box are cabled and terminate in a 22-contact female plug, PL–122, which fits into the corresponding pin plug, PL–122, in the receiver unit connector panel.

6. Loop assembly LP–21–LM includes the following components: loop antenna, loop-drive motor, compensator unit, and Autosyn transmitter unit.

7. The dehydrator unit contains silica gel mixed with cobalt chloride (blue). When saturated, the chloride turns pink.

8. The automatic indicator system consists, basically, of two specially designed synchronous electric motor-type units. Both have fixed Y-connected field windings. One motor, called the transmitter (MO–40), has its rotor geared to the loop, and the other motor, called the receiver, which is essentially the indicator unit, has its rotor connected to the indicator pointer. A 400-cycle ac is applied to each rotor. The field windings may be compared to the secondary of a transformer with movable primaries (rotors). Each field winding of the transmitter secondary is connected in parallel with the corresponding winding in the receiver. As the loop rotates, it rotates the rotor of the transmitter, inducing a voltage, which in turn is applied to the secondary (or stator) windings. Since the receiver windings are in parallel, the same voltages will be induced in their windings. The receiver rotor, being free to move, will rotate to a point similar to that of the transmitter. Thus, the position of the indicator pointer, through the synchro system, is locked (synchronized) to the position of the loop.

9. The 115-volt, 400-cycle ac is applied to the primary of power transformer 165.

10. The loop-relay, RE–14, is energized only on LOOP position of the function switch.

11. On band 4, the signal is coupled through *C*17 (1,000$\mu\mu$f) and switch *S*27A to the primary of input antenna transformer *T*47, where it is inductively coupled into the grid-tuned circuit. Some of the higher-frequency components of the signal are capacitively coupled directly to the grid through *C*107 (15$\mu\mu$f).

12. The i-f wave trap on band 2 in the first rf stage is *C*114–1 and *L*26 in parallel and resonates at 140.5 kc.

13. On ANTENNA position, the receiver volume control is actually the rf gain control, *R*79B, which is located in the remote-control box and is electrically in series with the cathode-to-ground circuits of the first rf, second rf, and mixer stages.

14. The gain of the i-f amplifier is reduced on loop operation by increasing the bias. The energized contacts *S*37B of RE–14 remove the ground connection between the two sensitivity controls (*R*49–2 and *R*49–3), thus placing additional resistance in the cathode-to-ground circuit of the i-f stage. This is done to keep the receiver sensitivity (or output) constant for each type of operation at any particular setting of the volume control.

15. The reference symbols and values of the given components are
    (*a*) diode avc load = $R18$–2, 1 megohm;
    (*b*) diode second detector load = $R12$–6 (100kΩ) and $R28$–1 (250kΩ);
    (*c*) diode second detector filter capacitors = $C14$ (100$\mu\mu$f) and $C13$–1 (50$\mu\mu$f);
    (*d*) audio feedback decoupling resistor = $R72$ (820kΩ).

16. The current through the tuning meter decreases as the set is tuned because the bias increases on the first af control grid as resonance is approached. This decreases total plate or cathode current through the tube and therefore through the meter, which is in series in the cathode-to-ground circuit.

17. The spark suppressor prevents arcing at the vibrating switch contacts, $S40$. Arcing burns the points and causes them to stick. The suppressor (rf filter) consists of $C97$ (0.01μf), $R5$–3 (25Ω), and $C94$ (0.05μf).

18. The loop-drive motor, MO–18A, is a two-phase ac, capacitor-type induction motor, which requires that its two field coils be excited by currents of the same frequency but 90° out of phase to cause rotation of the rotor. Twenty-eight-volt ac power is continuously supplied to the low-Z winding through a phasing capacitor, $C65A$, from terminal 10 of power transformer 165. The high-Z winding is supplied with 62 volts ac only when the loop is to be rotated in one direction or the other. This is done by the manually operated loop L-R switch ($S13$), which shifts the current phase 180° in the high-Z winding each time the switch connections are reversed. The phase relation between the currents in the two windings remains 90°, however; that is, if the current in the high-Z winding is leading that of the low-Z winding to produce rotation to the right, then it will lag the current in the low-Z winding by 90° to produce rotation to the left. The high-Z winding is also supplied with a dc polarizing voltage to prevent unwanted rotor movement.

19. To receive cw code, an 800-cycle ripple frequency from terminal 4 of the high-voltage secondary is coupled through capacitor $C28$–11 to the cw transformer, $T58$, whenever switch $S36$ in the control box is in cw position, thus energizing RE–12, which completes the 800-cycle signal circuit to the $T58$ primary. The tuned secondary is connected directly to the suppressor grid of the i-f amplifier tube, where the carrier is modulated with the 800-cycle tone.

20. The cardioid response pattern shows the resultant of the combined loop and sense-antenna voltages. Although the over-all cardioid response pattern does not change, the amount of voltage induced in the loop antenna does change as its position changes with respect to the direction of arrival of the received radio wave.

21. The receiver output which is fed to the synchronous rectifier (V_3 and V_4) is a pulsating dc voltage having a ripple frequency equal to that of the square-wave oscillator and an amplitude proportional to the resultant loop and sense-antenna voltages.

22. In figure 32 meter M measures the voltage difference between the plate load voltages of V_3 and V_4. The strength of this voltage depends upon the position of the loop with respect to the direction of the received signal.

23. For proper sense direction, the loop voltage must be either in phase or 180° out of phase with the sense-antenna voltage at the receiver input.

24. At exact null, the loop voltage is zero, leaving only the sense-antenna voltage. After detection, this produces equal and opposite voltages in the plate circuits of V_3 and V_4. The meter deflection is proportional to the difference between the two voltages, which is zero. The meter, therefore, will not deflect.

25. The loop must be rotated beyond its null point in one direction so that the other side of the loop is nearer the signal source. This causes a 180° change in the phase of the loop voltage.

26. In compass operation, as well as in antenna and loop operation, the dc and ac power are supplied through the closed contacts of power-input relay RE–8, which is energized by function-switch section $S35A$.

27. The loop-phaser circuit is used to shift the loop signal voltage 90°, which is necessary

to provide the zero- or 180-degree phase relationship between the loop and sense-antenna voltages.

28. The grids of the modulator are connected in parallel, and the plates are connected in push-pull with respect to the loop signal.

29. Actually, the purpose for grounding the modulator cathode through contact *S*37D of RE–14 is to short out *R*80, which is not used during compass operation. This ground is removed when RE–14 is energized during loop operation.

30. The 48-cycle oscillator and cathode-follower circuits are disabled during antenna and loop operation by removing the *B*+ voltage. This is done through contacts *S*37F of RE–14 on loop operation and through contacts *S*38A of RE–13 on antenna operation.

31. An R-C filter composed of *C*87 and *R*38–4 rejects all frequencies higher than 60 cycles from the grid circuit of the compass output stage.

32. The diode section is connected in a full-wave rectifier (detector) circuit. A portion of the 48-cycle from the filter jack is rectified, and a bias voltage is developed across load resistor *R*49 (variable) and *R*57. This voltage is filtered and applied to the loop-amplifier tube as avc voltage. The gain is thereby regulated to maintain at all times the best relationship between the loop and antenna components combined in transformer *T*44. This same avc voltage is also applied to the grid circuits of the loop-control tubes and therefore determines when either of the tubes will fire in accordance with the strength of the 48-cycle voltage from the filter jack.

33. The additional stages required for compass operation are the loop amplifier, the balanced modulator, the 48-cycle oscillator, the compass output and loop avc, the cathode follower, and the loop-control tubes.

34. Loop amplifier amplifies the loop antenna signal and thereby maintains the proper relationship between the loop and sense-antenna signals. The parallel resonant phaser circuit in its plate circuit retards the loop signal 90°.

Balanced modulator (see fig. 34): Since the same phase of loop rf signal is applied to both grids, the loop voltage would be canceled in the push-pull-connected plate circuit. When the loop rf is superimposed on a 48-cycle audio signal connected in push-pull in the grid circuit, the proper phase of the loop signal is amplified in the plate circuit. After the modulator output is combined with the sense-antenna signal, the resultant rf signal will have a 48-cycle amplitude variation. If this signal is in phase with the 48-cycle af synchronizing voltage, it will cause (after detection) one of the loop-control tubes to fire; if out of phase, the other loop-control tube will fire.

The 48-cycle oscillator develops the synchronizing voltage applied to the modulator and loop-control tubes. Depending upon the position of the loop, it is the 48-cycle voltage that will make the grid and plate of one or the other loop-control thyratrons positive at the same instant (synchronized).

Compass output and loop avc stage amplifies the 48-cycle component of the detected rf signal (resultant of the modulator output and sense-antenna signals before detection) and also develops the avc voltage for the loop and loop-control tubes.

Cathode follower develops the 48-cycle pulsating dc voltage for the loop-control tube plate circuits.

Loop-control tubes: These tubes with the saturable reactors associated with their plate circuits replace the manually controlled loop left-right switch, which allowed 400-cycle ac current to flow through the high-*Z* winding of the loop-drive motor, thereby causing the motor to rotate. When one of the loop-control tubes fires, the resulting current flow saturates the associated reactor, causing the impedance of the secondary winding to fall off and approach its dc resistance. This is comparable to closing the loop left-right switch, in that the 400-cycle current will not flow through the high-*Z* winding and will therefore not cause the loop-drive motor to rotate.

CHAPTER 3

1. The special adapter is necessary in making voltage measurements because the junction-box terminals have been incorporated in the

mounting. The adapter makes the terminals accessible, since the receiver is removed from the mounting.

2. The i-f trap is effective in bands 2, 3, and 4.

3. The receiver is connected to the remote-control units through connectors *P*102 (male), *J*501 (female), junction points and relay *K*501 in the mounting (MT–273), *J*302, and the associated interconnecting cables.

4. *P*102 is the male connector located at the rear of the receiving unit, making direct contact to the mounting through female connector *J*501. *P*102 has 22 banana-type contacts, 19 of which are used. The contacts are spaced $\frac{3}{8}$ inch apart in a straight line. The dimensions of the phenalic strip are $9\frac{11}{16} \times \frac{5}{6} \times \frac{5}{64}$ in.

5. The Autosyn motors of the ARN–6 are energized with 100-cycle ac power, whereas in the ARN–7 they were energized with 400-cycle ac power. This, of course, necessitates some change in the design of the windings and other component parts.

6. Stages required for antenna operation are the first and second rf, first detector, first and second i-f, second detector, audio driver, and two audio power output stages connected in push-pull.

7. Additional stages required for loop operation are the loop amplifier and one half of the modulator stage operating as an rf amplifier.

8. The tuning-indicator rectifier and amplifier stages are used to operate the tuning meter.

9. The stages required for automatic loop operation are the balanced modulator, compass amplifier, two loop-control tubes, and vibrator.

10. Oscillators required for code reception are the tone and beat-frequency oscillators.

11. The commercial numbers and names of the various tubes used in the AN/ARN–6 are as follows:

    12SK7—Remote-cutoff pentode
    12SX7—Dual triode
    12SY7—Pentagrid converter
    12SW7—Duo-diode triode
    26A7GT—Beam power tetrode
    2050—Gas thyratron.

12. The various circuits and devices to which ac power is applied are the balanced modulator, loop-control tubes, loop left-right switch, indicators, Autosyn transmitter, and loop-drive motor.

13. The following pairs of tube heaters are connected in series-parallel across 26.5 volts dc:

*V*114 and *V*108:	Compass amp and ind detector
*V*106 and *V*107:	First i-f amp and second i-f amp
*V*101 and *V*103:	Loop amp and first rf amp
*V*104 and *V*105:	Second rf amp and first detector
*V*102 and *V*109:	Modulator and rf and tone oscillators
*V*113 and *V*110:	BFO and tuning ind rect, and af driver and tuning ind amp.

14. Terminals 31 and 29–30 in the mounting are used for the *A*+ and *A*− terminals, respectively.

15. The antenna relay (*K*102) is energized by grounding one side of its solenoid through contacts 6A and 8A of *S*305A, thus completing the energizing circuit, since the other side is connected to the *A*+ line.

16. Rotor contact 3 of *K*102 closes the *A*+ line to either the compass amplifiers in the relaxed position or the BFO in the energized position.

17. Section E of *C*111 tunes the rf oscillator. Its capacitance range is 12.5 to 405 micromicrofarads.

18. The components listed are used as follows: *R*154, first af plate load; *R*168, af driver grid load; *C*1139, coupling capacitor.

19. The purpose of the feedback circuit between the audio output and driver stages is to increase the gain of the higher audio frequencies.

20. On COMPASS position, the audio output is controlled by a bridged-T network connected in the audio line to the headset jack. The network divides the output voltage so that the portion tapped off *R*302B appears across the headphones and *R*303 in series. However,

the level of af voltage depends upon the output from $T105$, the setting of the volume control, and the resulting current flow through the network circuit.

21. In a reversed-current type of tuning meter, full-scale current will flow through the tuning meter when the receiver is not tuned to any station. As the receiver is tuned to a station, the current through the meter will decrease, resulting in a minimum current flow (or maximum dip) at exact resonance.

22. The band 2 motor-circuit electron flow is traced as follows, starting from ground ($A-$) at terminal 6 of $B101$: Electrons will flow from ground through the armature ($-$ to $+$) and the right-hand field winding to terminals 2–J through line J to J–24 at $J501$, then to terminal 24 at $K501$, through the relay contacts, line 6, to terminal K at $J302$, which connects to contact 1 of $S303$. The circuit is completed to the $A+$ line through the rotor contact 5 of $S303$.

23. The $K501$ solenoid is tapped through a spring-type switch. When the solenoid is energized, the switch opens, cutting in the high-resistance sections of the coil, which reduces the current, thereby preventing the overheating of the coil.

24. Relaxed contact 5 of $K101$ shorts $R184$ and $R1109$ in the cathode circuit of the first i-f stage.

25. The vibrator itself merely interrupts the flow of dc very rapidly, but when a dc suddenly starts or stops flowing through a highly inductive primary coil, the transformer reacts to it as it would to any changing current. In short, a distorted ac voltage is developed across the secondary.

26. The voltage-phasing network is used to shape the distorted 100-cycle ac from the secondary of $T107$ into a pure sine wave, which is applied as the synchronizing voltage to the modulator through $T119$.

27. The current through the low-Z winding is made to lead the applied voltage by about 90° because capacitor $C1150B$ is placed in series with the ac line (line F at terminal 8, $J102$). Since the voltages to the two motor windings are applied in phase from the same source, the two currents are 90° out of phase, which is necessary to produce rotation in this split-phase motor. $C1150A$ across the high-Z winding also helps to insure the proper phase.

28. No, the loop left-right switch and the loop-control tubes do not perform different functions. They both cause the loop-drive motor to rotate to the right or left by supplying the proper phase of current to the high-Z winding. However, the switch is manually operated and the loop-control tubes are automatically controlled.

29. At zero torque, the rotors are alined, inducing equal and opposite voltage in the coils of each stator winding. The resultant winding voltage is zero; therefore, no current flows through the windings. When torque (tuning force) is present, the generator rotor has been mechanically rotated, inducing different voltages in its stator, and current flows. This produces a magnetic force that is strongest in a direction in line with the rotor. Since the motor (indicators) stator coils are connected in parallel with the corresponding generator coils, they will set up the same resultant magnetic force, causing the rotors to be pulled in line with this force.

30. The firing of either loop-control tube depends upon the phase of the synchronizing voltages applied to the grid and plate circuits of the loop-control tubes. When the grid and plate voltages are positive at the same instant, that tube will conduct, causing loop rotation in one direction until the null position is reached. For the other tube to fire, the loop would need to rotate past the null point so that the voltage in the other side of the loop would predominate. This would, of course, change the phase of the loop signal 180°, and the loop (loop motor) would rotate in the opposite direction.

31. Loop hunting is reduced to a minimum by a negative feedback system. A portion of the 100-cycle source is applied out of phase to the original signal applied at the compass am-

plifier grid circuit. This reduces the output and tends to prevent sporadic firing of the control tubes.

32. The rf and i-f sections of the receiver can be checked by observing the operation of the tuning meter.

$$P_0 = \frac{E^2}{R}$$

$$\frac{\cancel{50}^{\,1}}{1} = \frac{x}{\cancel{2500}\ 50}$$

~~x = 50~~

$$P_0 = \frac{E^2}{R}$$

$$\begin{array}{r} 15 \\ 15 \\ \hline 75 \\ 15 \\ \hline \end{array}$$

$$50 = \frac{10E^2}{25}$$

$$10E^2 = 1250$$

$$= \sqrt{125}$$